US007434918B2

(12) **United States Patent**
Sugahara

(10) **Patent No.: US 7,434,918 B2**
(45) **Date of Patent: Oct. 14, 2008**

(54) LIQUID TRANSPORTING APPARATUS AND METHOD FOR PRODUCING LIQUID TRANSPORTING APPARATUS

(75) Inventor: **Hiroto Sugahara**, Aichi-ken (JP)

(73) Assignee: **Brother Kogyo Kabushiki Kaisha**, Nagoya (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 435 days.

(21) Appl. No.: **11/261,223**

(22) Filed: **Oct. 27, 2005**

(65) **Prior Publication Data**

US 2006/0152556 A1 Jul. 13, 2006

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/310,750, filed on Dec. 5, 2002, now Pat. No. 6,971,738.

(30) **Foreign Application Priority Data**

Dec. 6, 2001	(JP)	2001-372104
May 8, 2002	(JP)	2002-132195
Sep. 27, 2002	(JP)	2002-284304
Oct. 27, 2004	(JP)	2004-312840

(51) **Int. Cl.**
B41J 2/045 (2006.01)
(52) **U.S. Cl.** **347/71**
(58) **Field of Classification Search** 347/68, 347/70–72
See application file for complete search history.

(56) **References Cited**

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2003/0107622	A1	6/2003	Sugahara

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Primary Examiner—An H Do
(74) *Attorney, Agent, or Firm*—Reed Smith LLP

(57) ABSTRACT

An ink-jet head **501** as a liquid transportation apparatus includes pressure chambers **514**, and a piezoelectric layer **503** having individual electrodes **532** and a vibration plate **530**. When W is a length in the radial direction of pressure chambers **514**, and A is a length in the radial direction of portions of individual electrodes **532** to which a drive voltage is applied, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers **514**, the length A in the radial direction of individual electrodes **532** is determined based on a relationship between the value of A/(W/2) and an amount of deformation of the vibration plate **530** when the drive voltage is applied to the individual electrode **532**, such that the amount of the deformation of the vibration plate **530** becomes great. Accordingly, a liquid transporting apparatus provided with the piezoelectric actuator which has excellent durability and more improved drive efficiency.

29 Claims, 41 Drawing Sheets

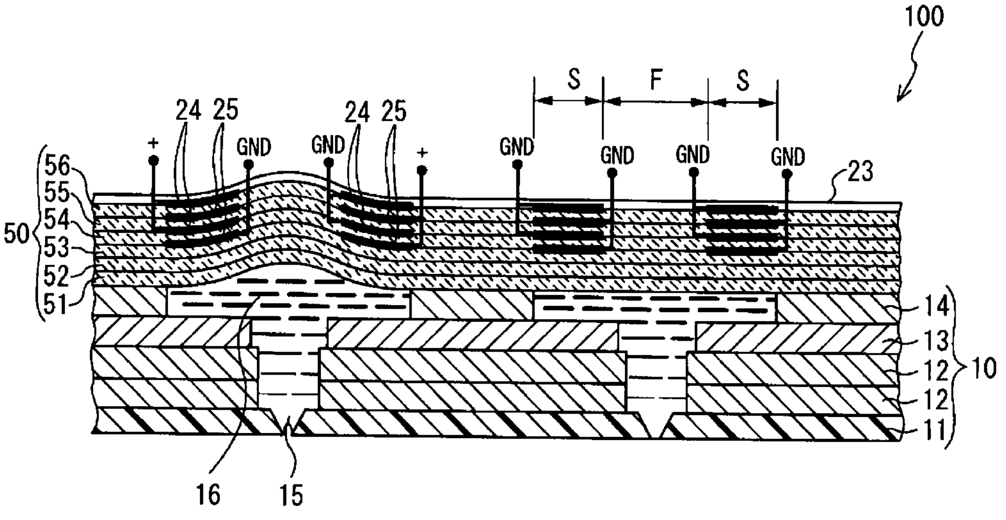


FIG. 1

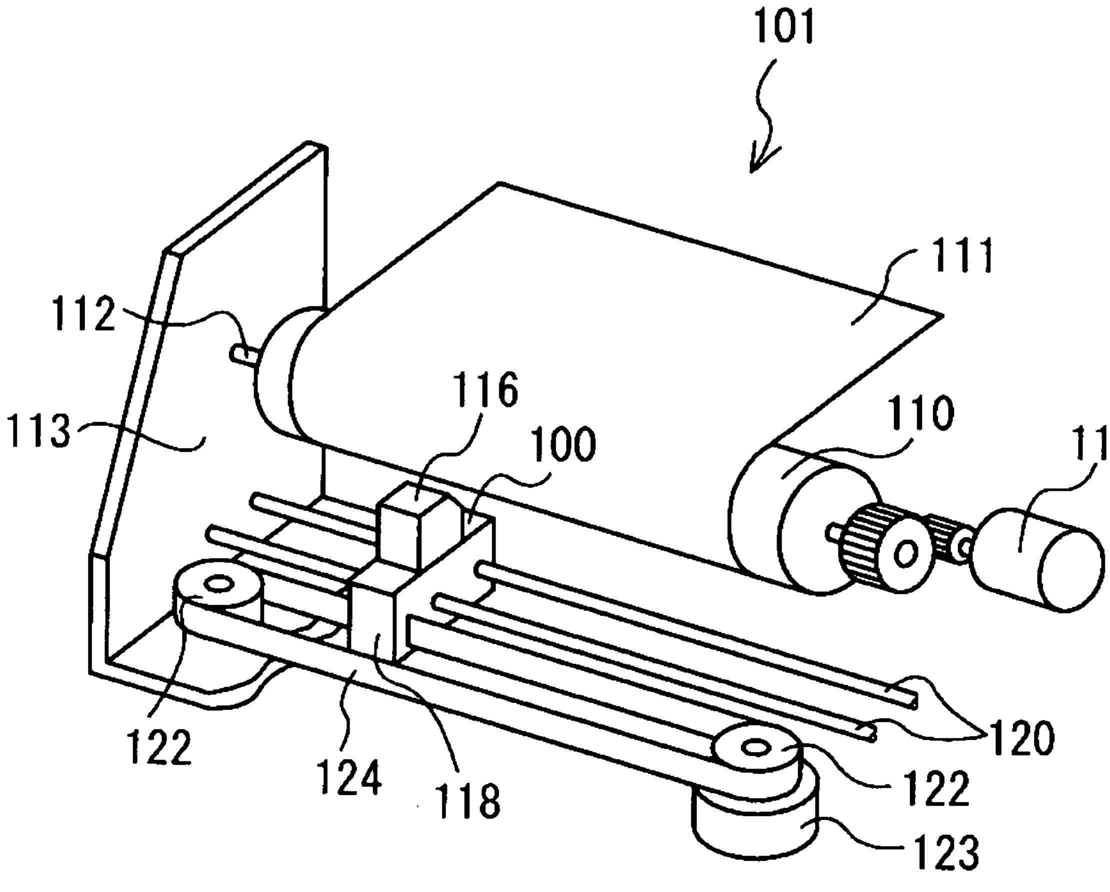


FIG. 2

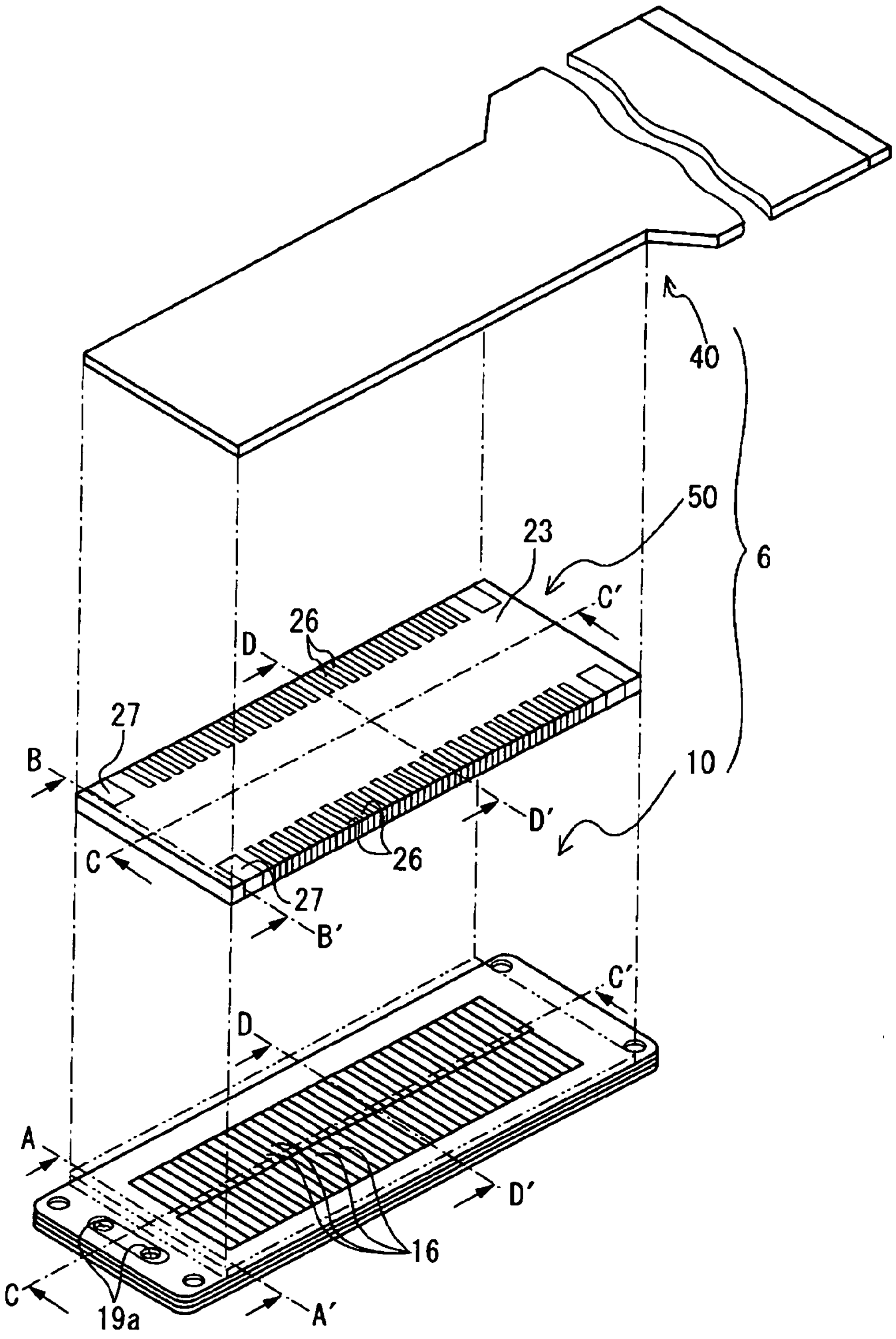


FIG. 3

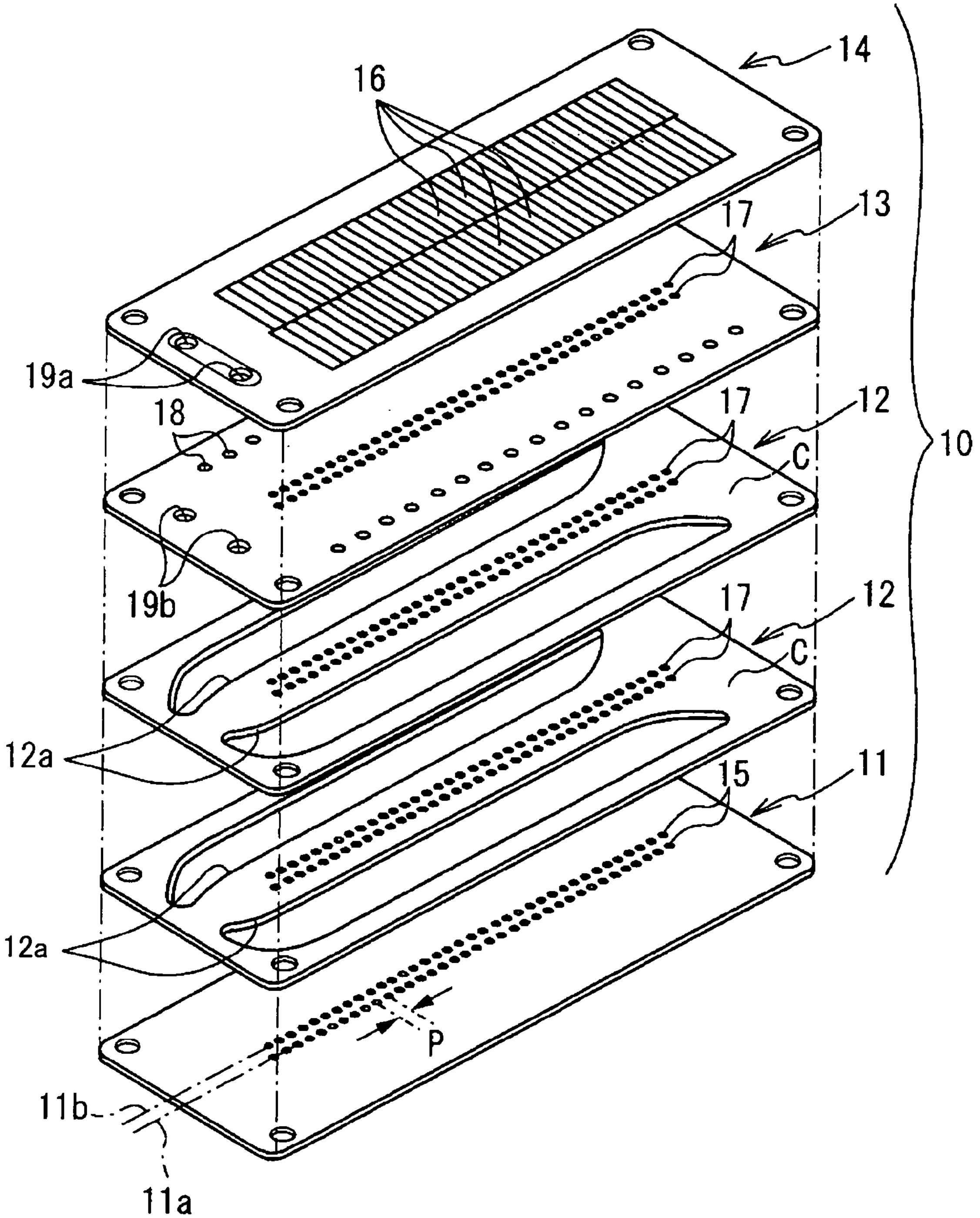


FIG. 4

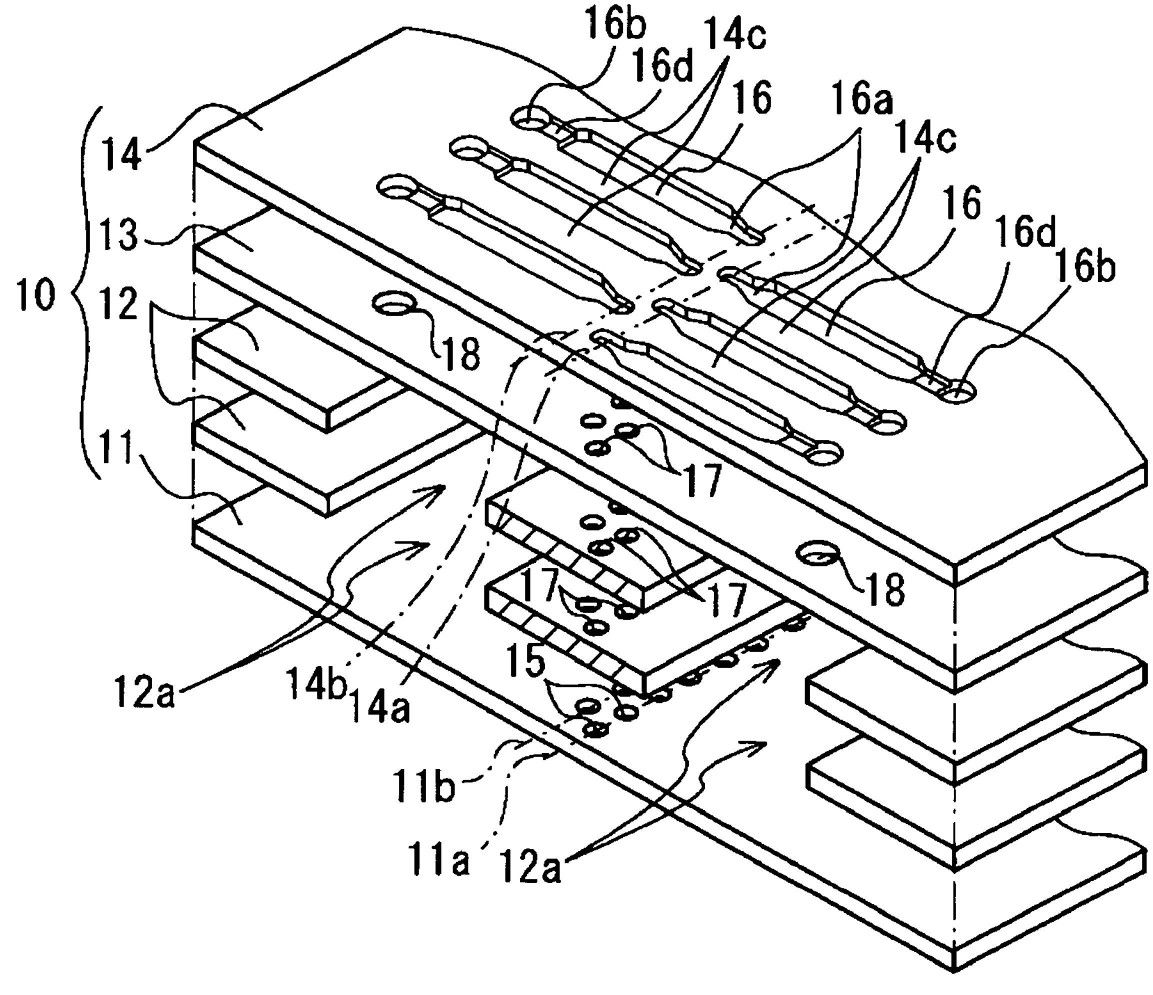

16b
16d
14c
16
16a
14c
16
16d
16b
14
13
10
12
18
11
17
17
17
18
15
12a
14b
14a
11b
11a
12a

FIG. 5

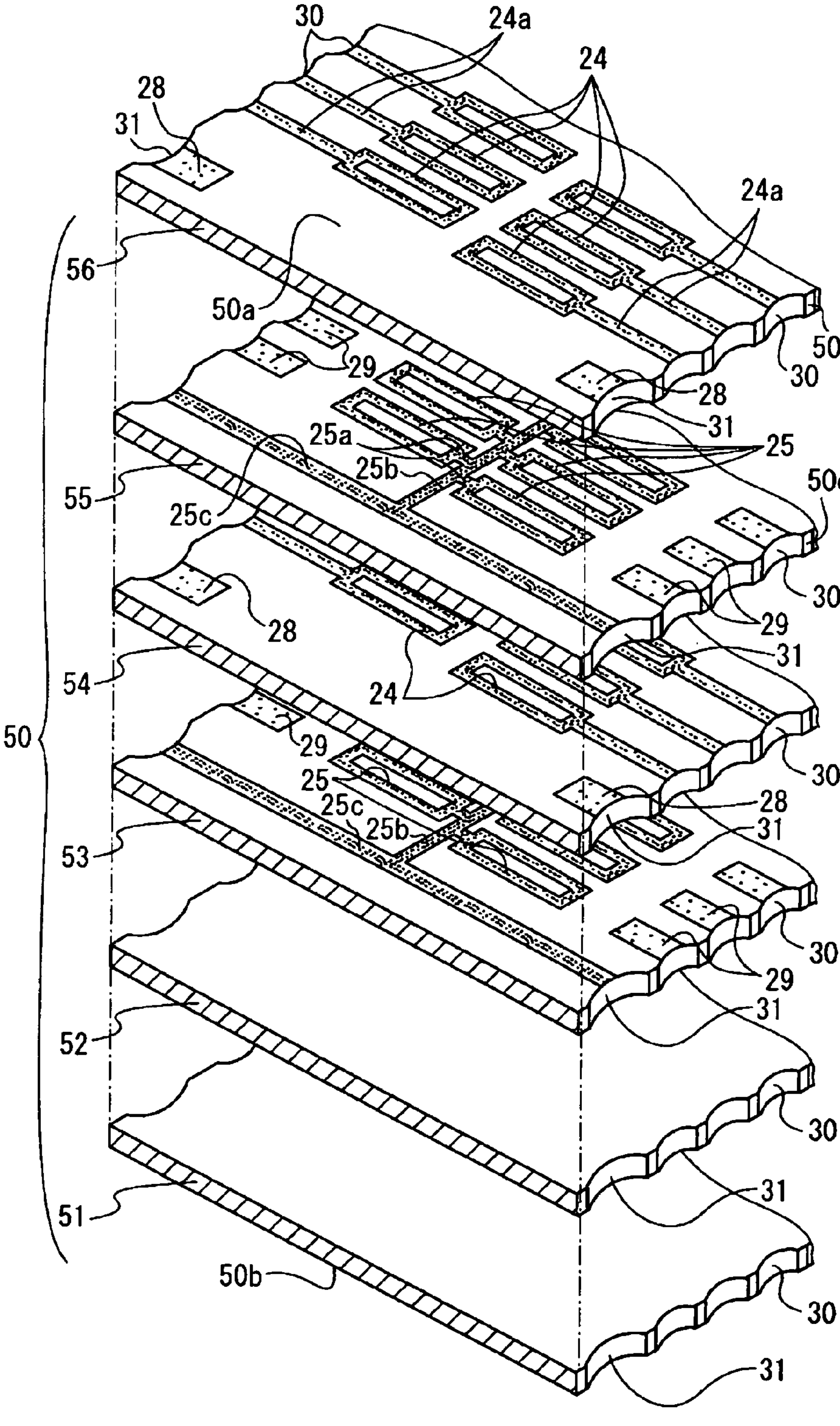

30
24a
24
28
31
24a
56
50a
50c
30
29
28
31
25
25a
25b
55
25c
50c
30
29
28
31
54
24
50
29
25
25c
25b
30
28
31
53
30
29
31
52
30
31
51
30
50b
31

FIG. 6

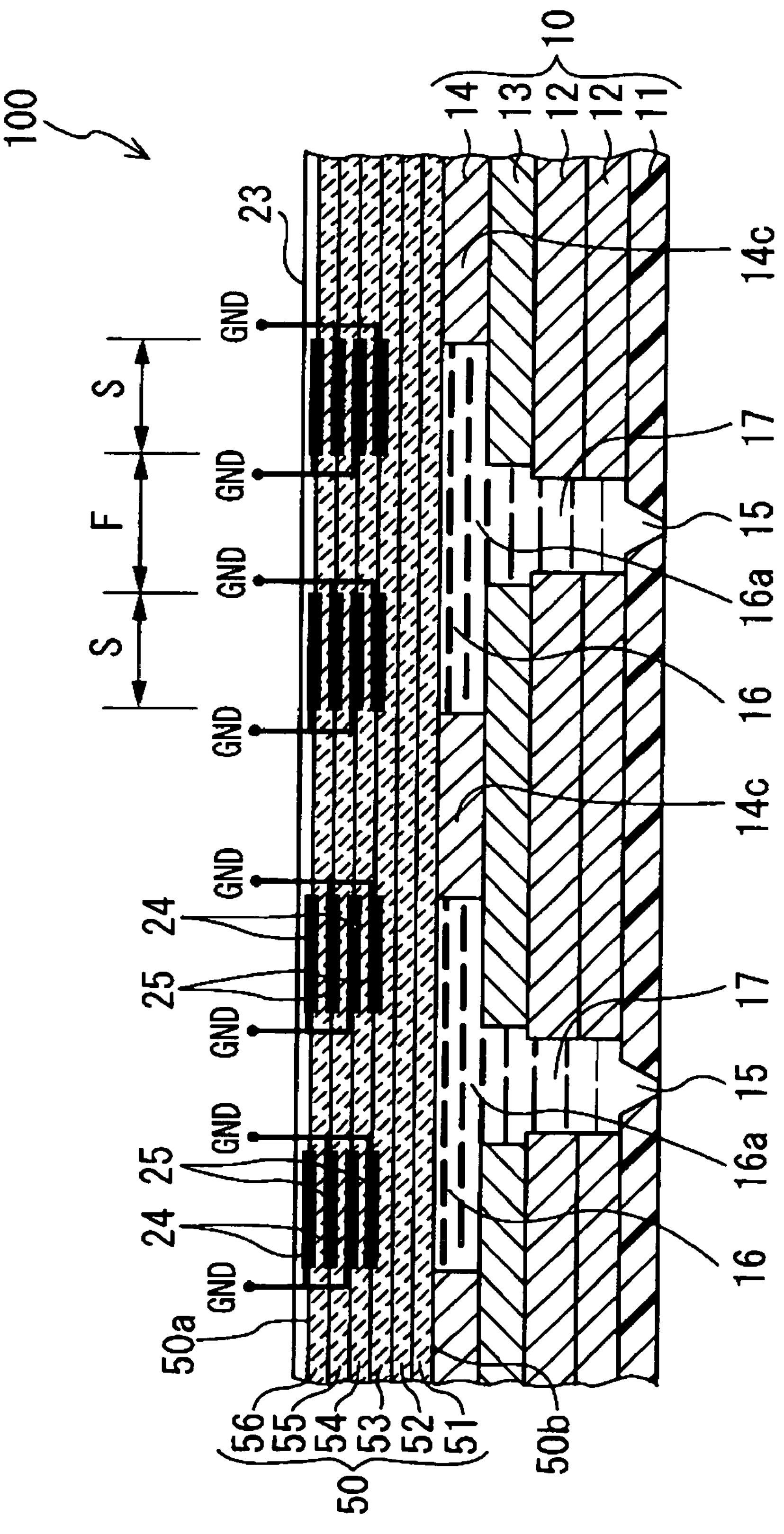

100
10
14
13
12
12
11
23
14c
S
F
S
GND
GND
GND
GND
GND
GND
GND
GND
17
15
16a
16
14c
24
25
24
25
17
15
16a
16
50a
56
55
54
53
52
51
50b
50

FIG. 7

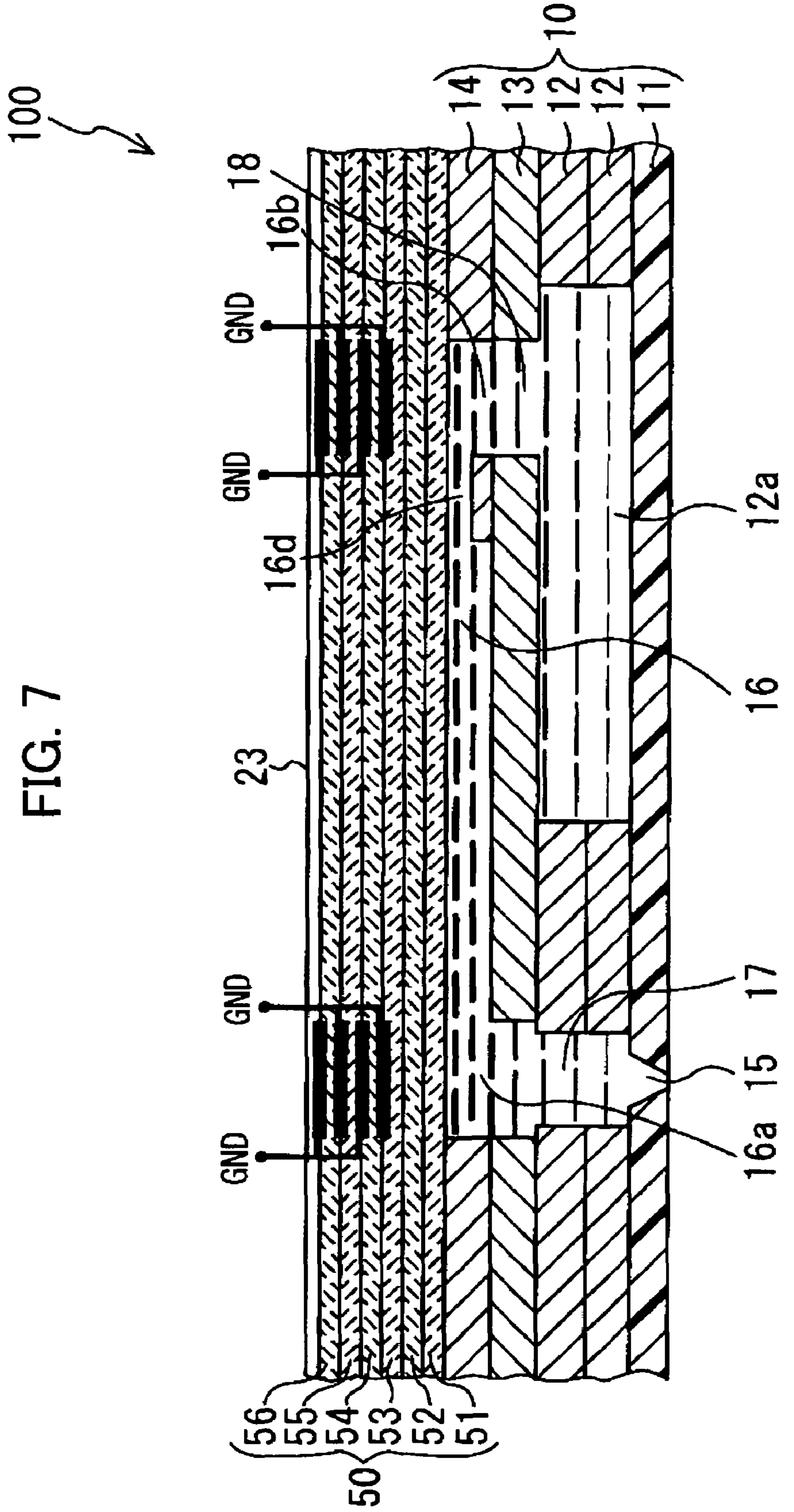

100
10
14
13
12
12
11
18
16b
GND
GND
12a
16d
16
23
GND
GND
17
15
16a
56
55
54
53
52
51
50

FIG. 8

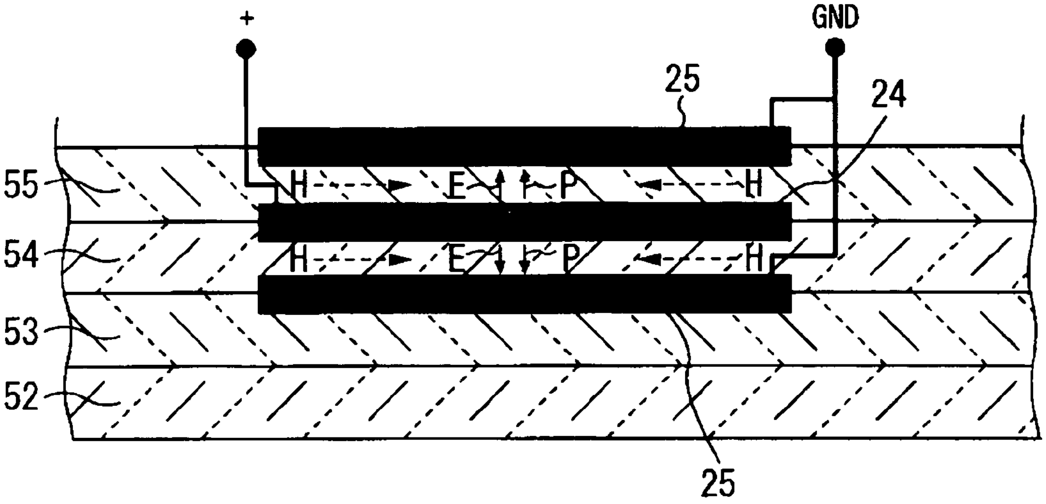


FIG. 9

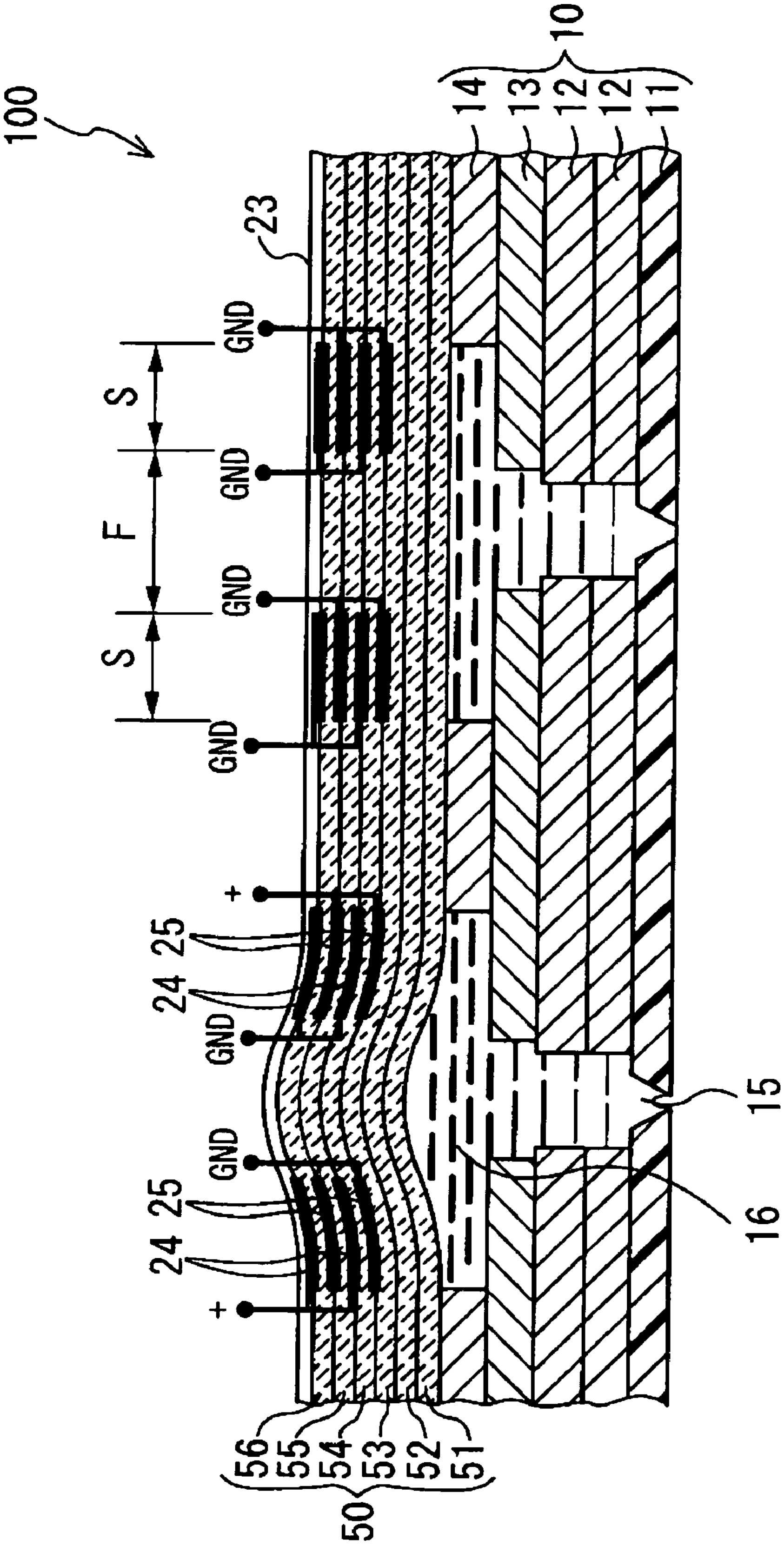

100
23
10
14
13
12
12
11
S
F
S
GND
GND
GND
GND
+
24
25
GND
GND
25
24
+
15
16
56
55
54
53
52
51
50

FIG. 10

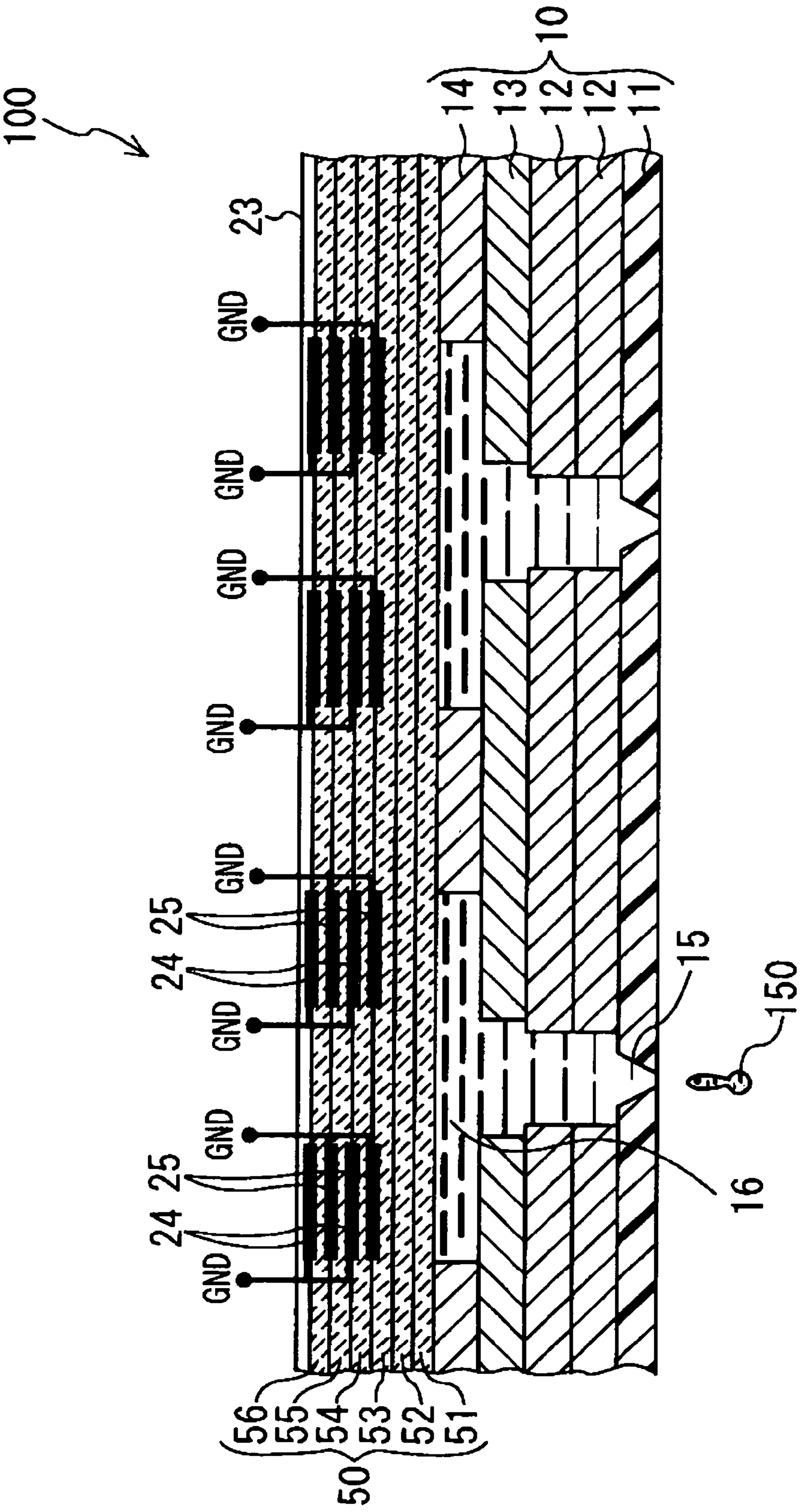

100
10
14
13
12
12
11
23
GND
GND
GND
GND
GND
GND
GND
GND
24
25
24
25
15
150
16
56
55
54
53
52
51
50

FIG. 11

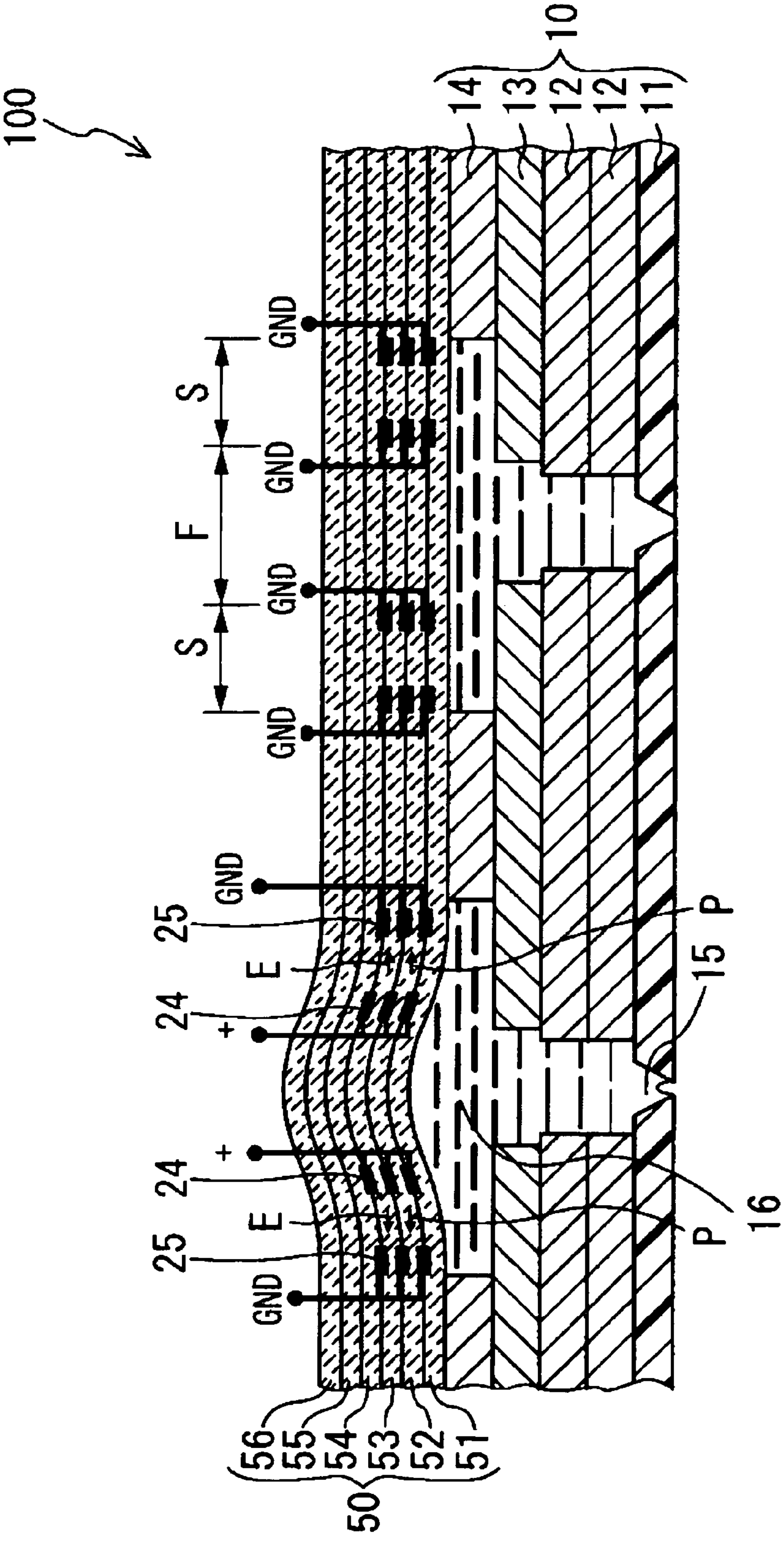

100
10
14
13
12
12
11
S
F
S
GND
GND
GND
GND
GND
GND
25
E
24
+
+
24
E
25
P
15
P
16
50
56
55
54
53
52
51

FIG. 12

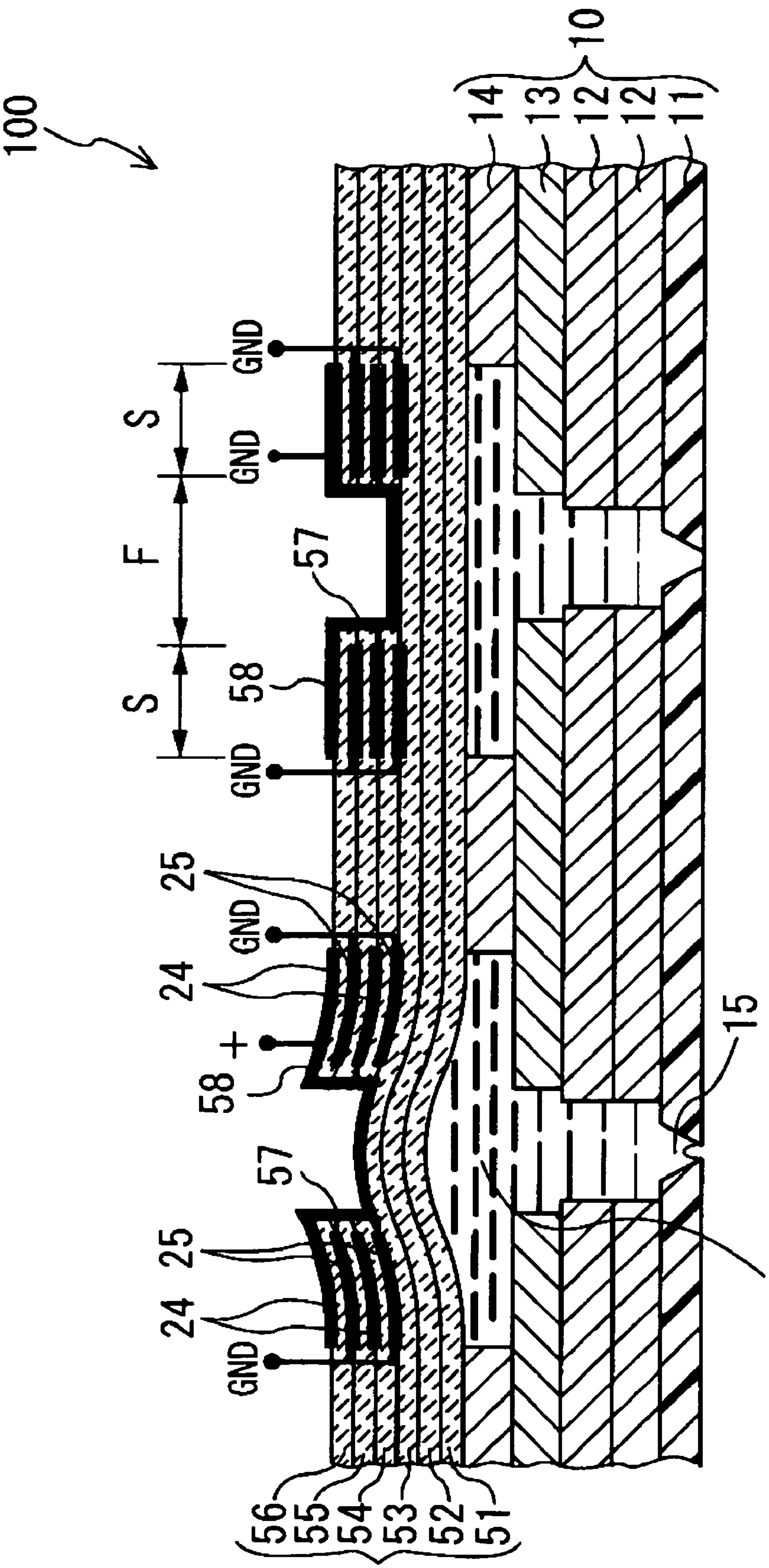

100
10
14
13
12
12
11
GND
S
GND
GND
F
57
S
58
GND
25
GND
24
+
58
15
57
25
24
GND
16
56
55
54
53
52
51
50

FIG. 13

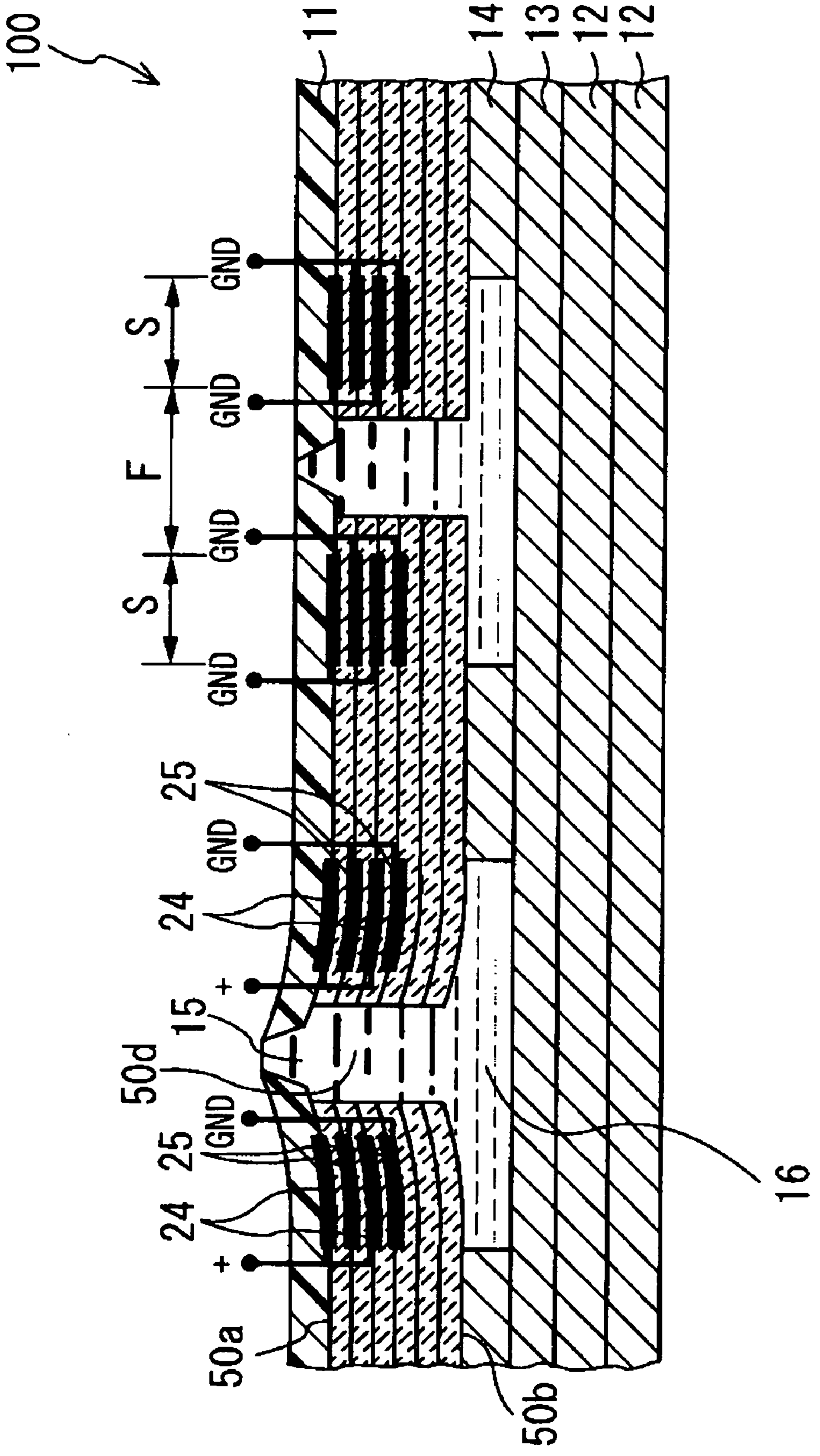

100
11
14
13
12
12
GND
S
GND
F
GND
S
GND
25
GND
24
+
15
50d
GND
25
24
+
50a
50b
16

FIG. 14

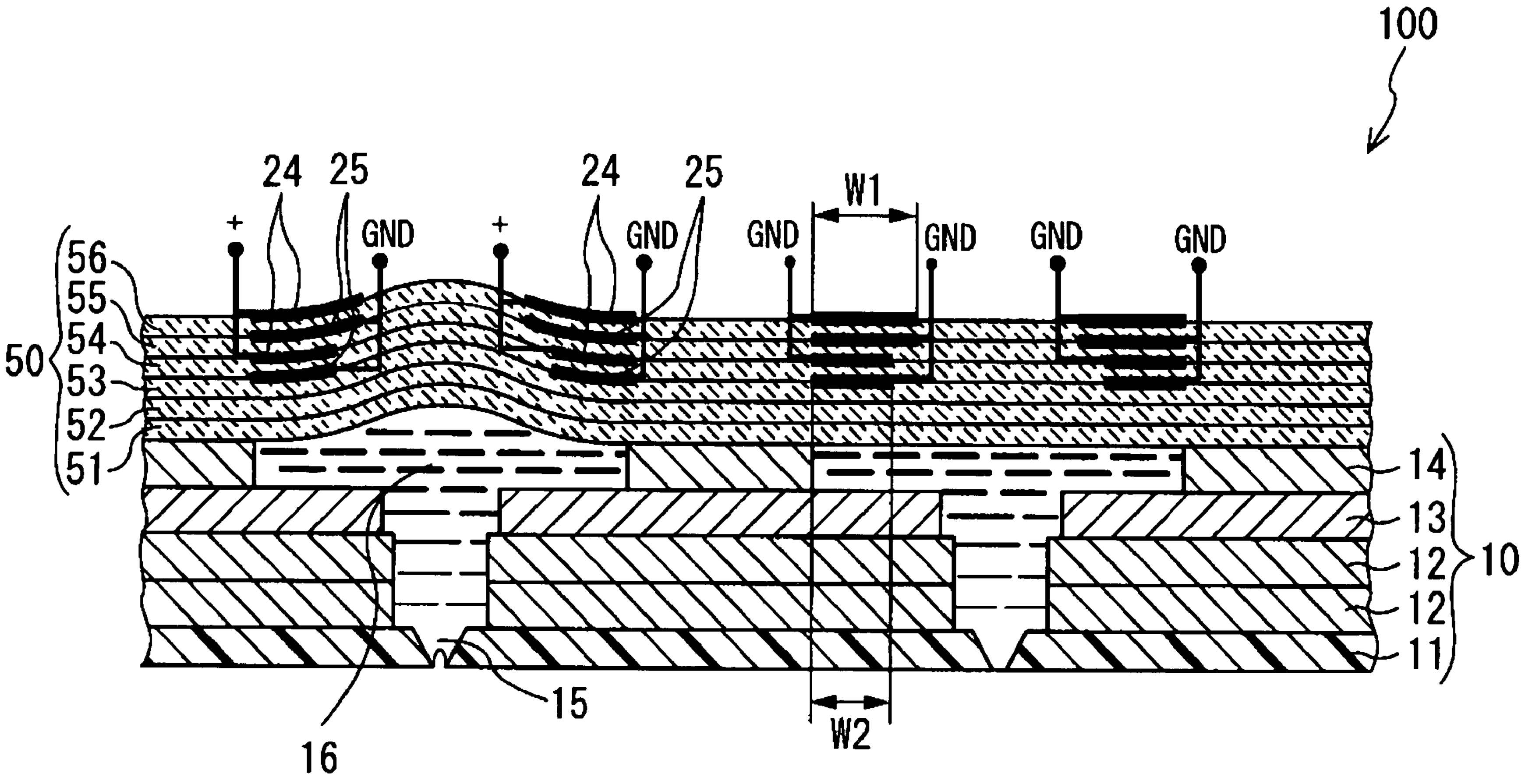

100
24
25
24
25
W1
+
GND
+
GND
GND
GND
GND
GND
56
55
54
53
52
51
50
14
13
12
12
11
10
15
16
W2

FIG. 15

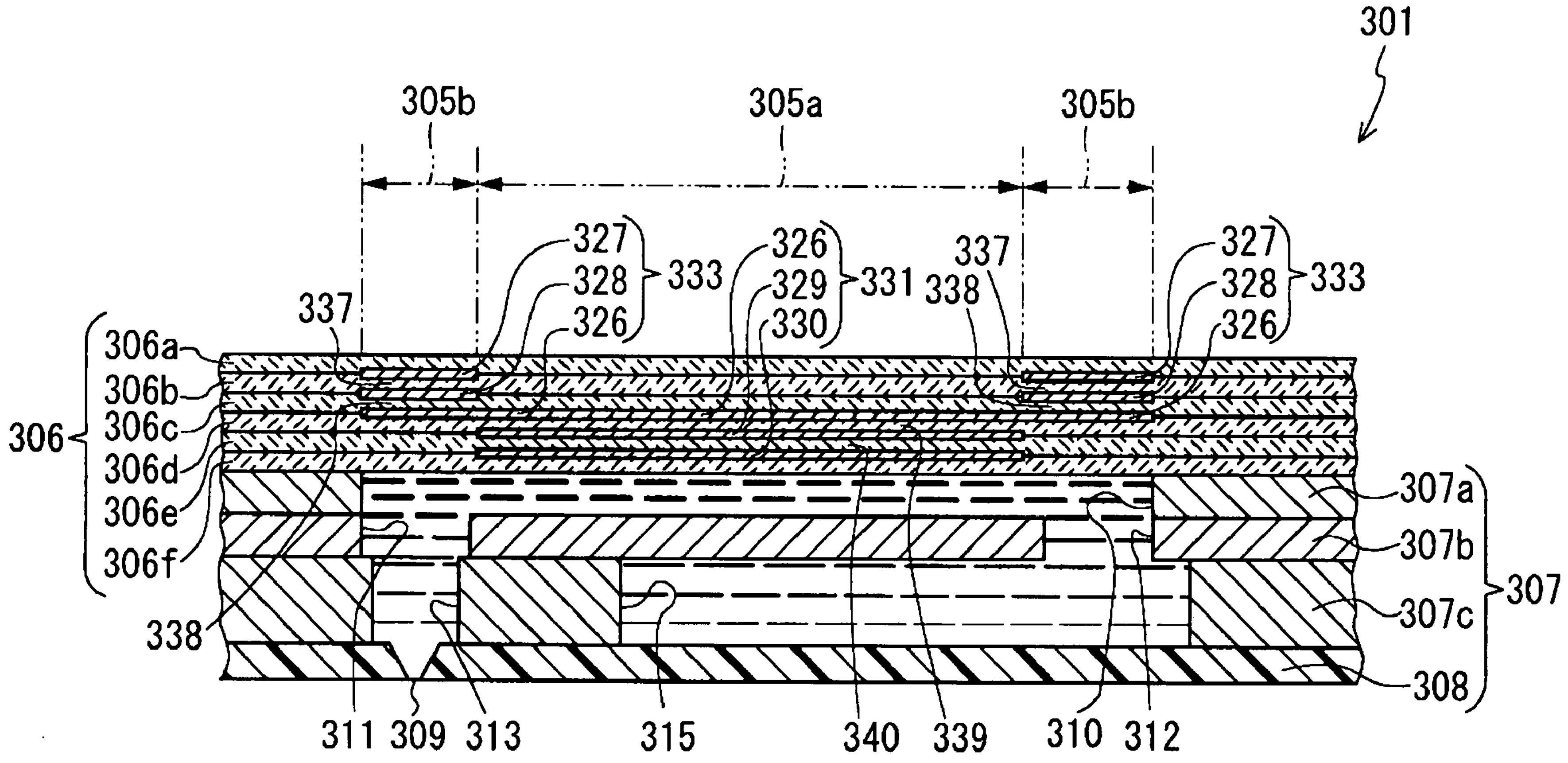

301
305b
305a
305b
327
328
326
333
326
329
330
331
337
338
327
328
326
333
337
306a
306b
306c
306d
306e
306f
306
338
307a
307b
307c
307
308
311
309
313
315
340
339
310
312

FIG. 16

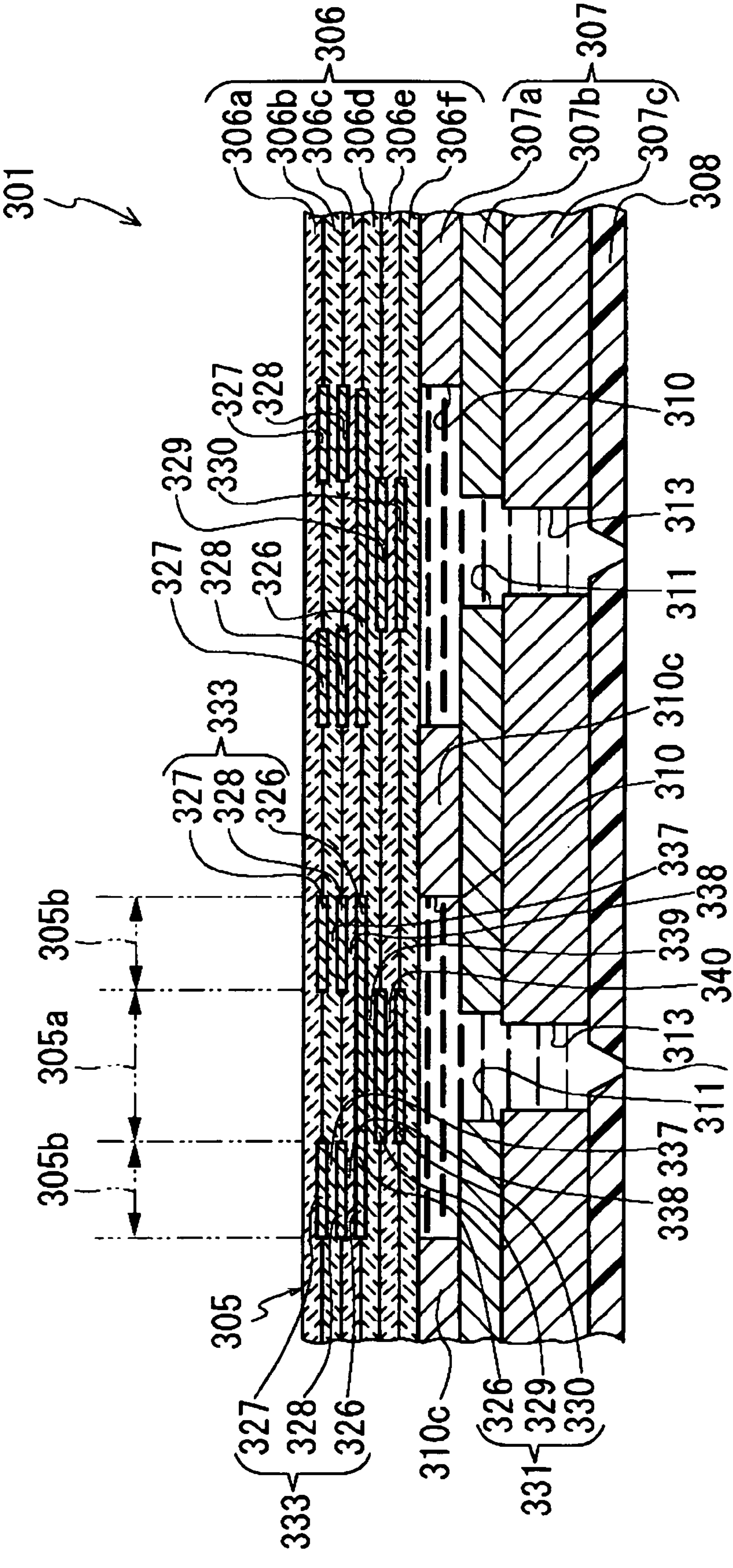

301
306
306a
306b
306c
306d
306e
306f
307
307a
307b
307c
308
327
328
329
330
327
328
326
333
327
328
326
305b
305a
305b
305
310
313
311
310c
310
337
338
339
340
313
311
309
337
338
327
328
326
333
310c
326
329
330
331

FIG. 17

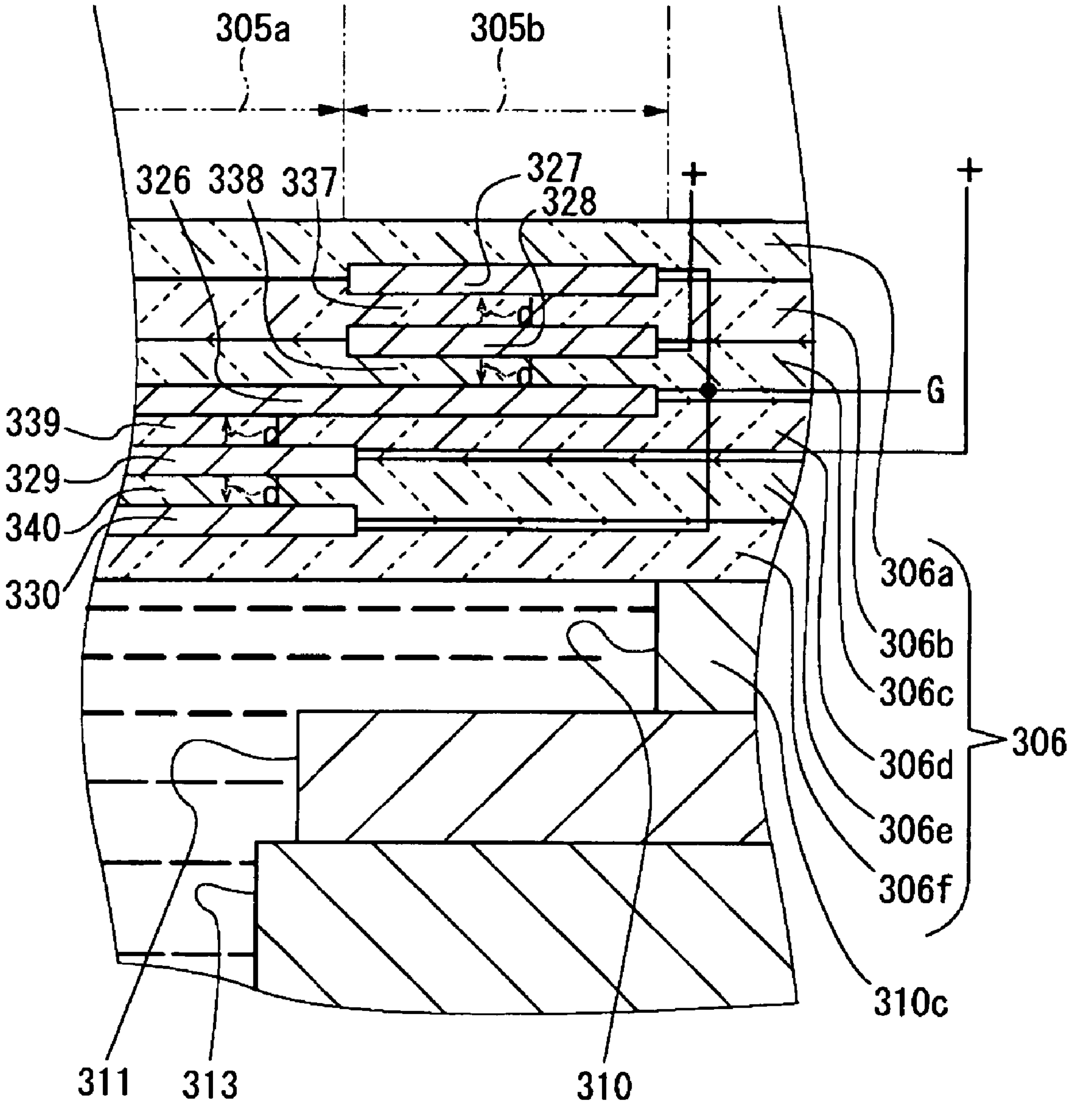

305a
305b
326
338
337
327
328
+
+
G
339
329
340
330
d
d
d
d
306a
306b
306c
306d
306e
306f
306
310c
311
313
310

FIG. 18

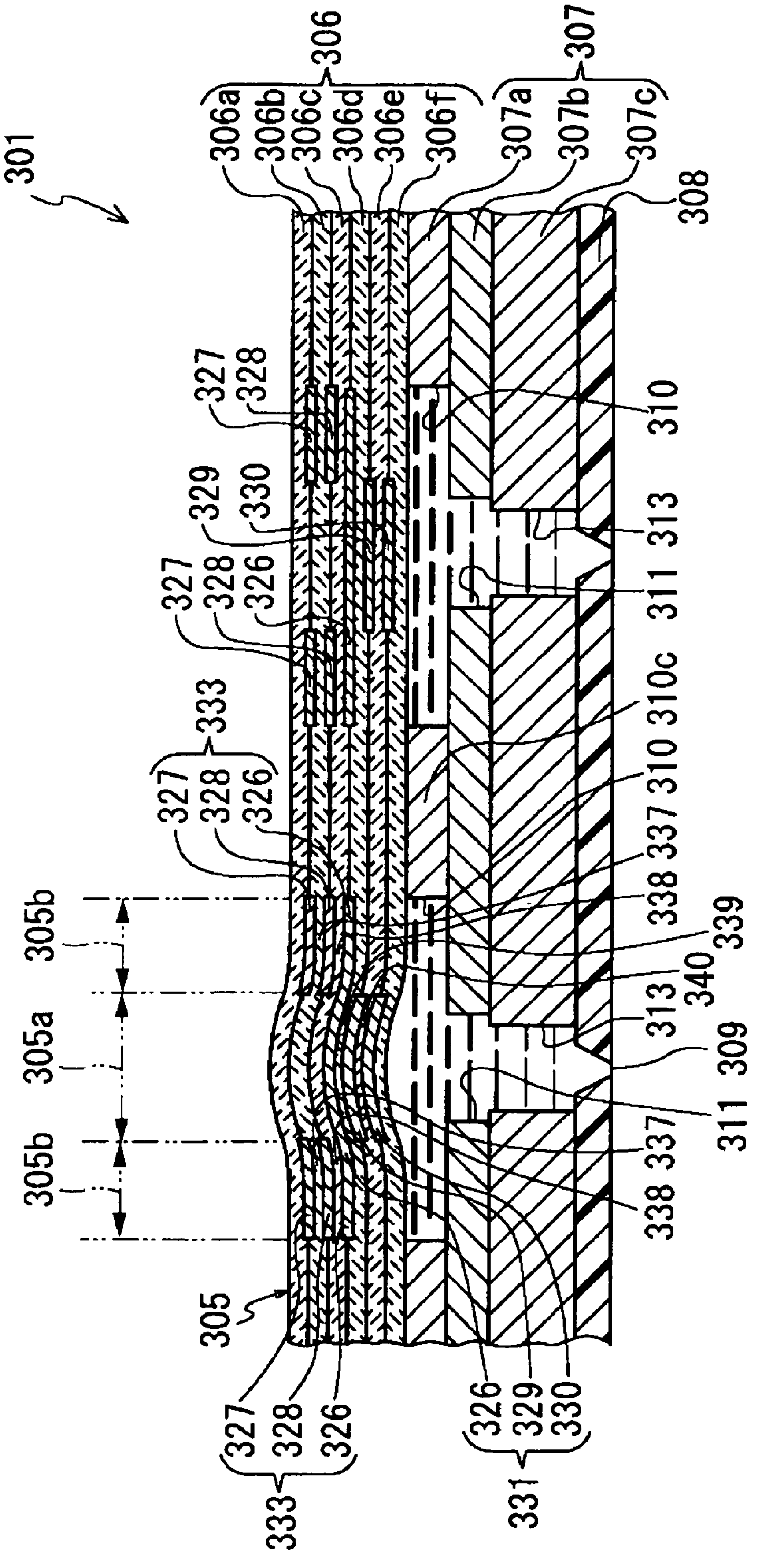

301
306
306a
306b
306c
306d
306e
306f
307
307a
307b
307c
308
327
328
329
330
310
313
311
326
333
310c
337
338
339
340
309
305b
305a
305
331

FIG. 19

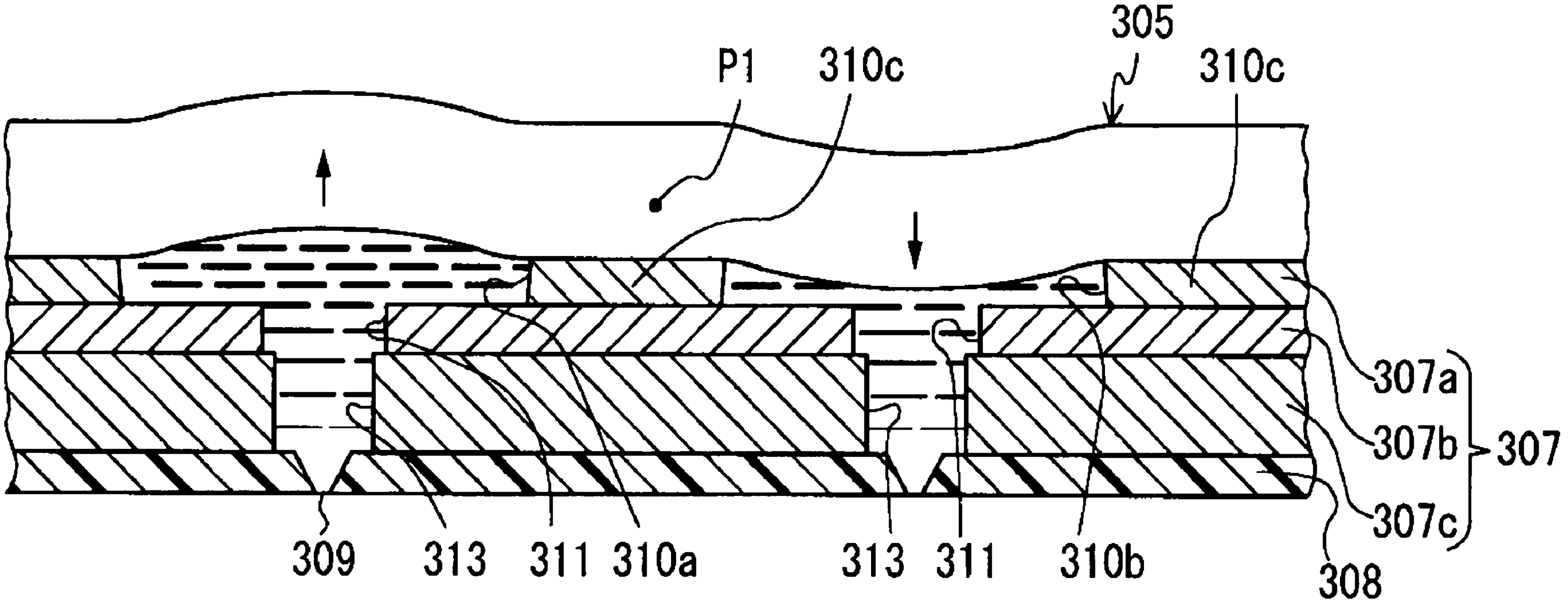

305
P1
310c
310c
307a
307b
307
307c
308
309
313
311
310a
313
311
310b

FIG. 20

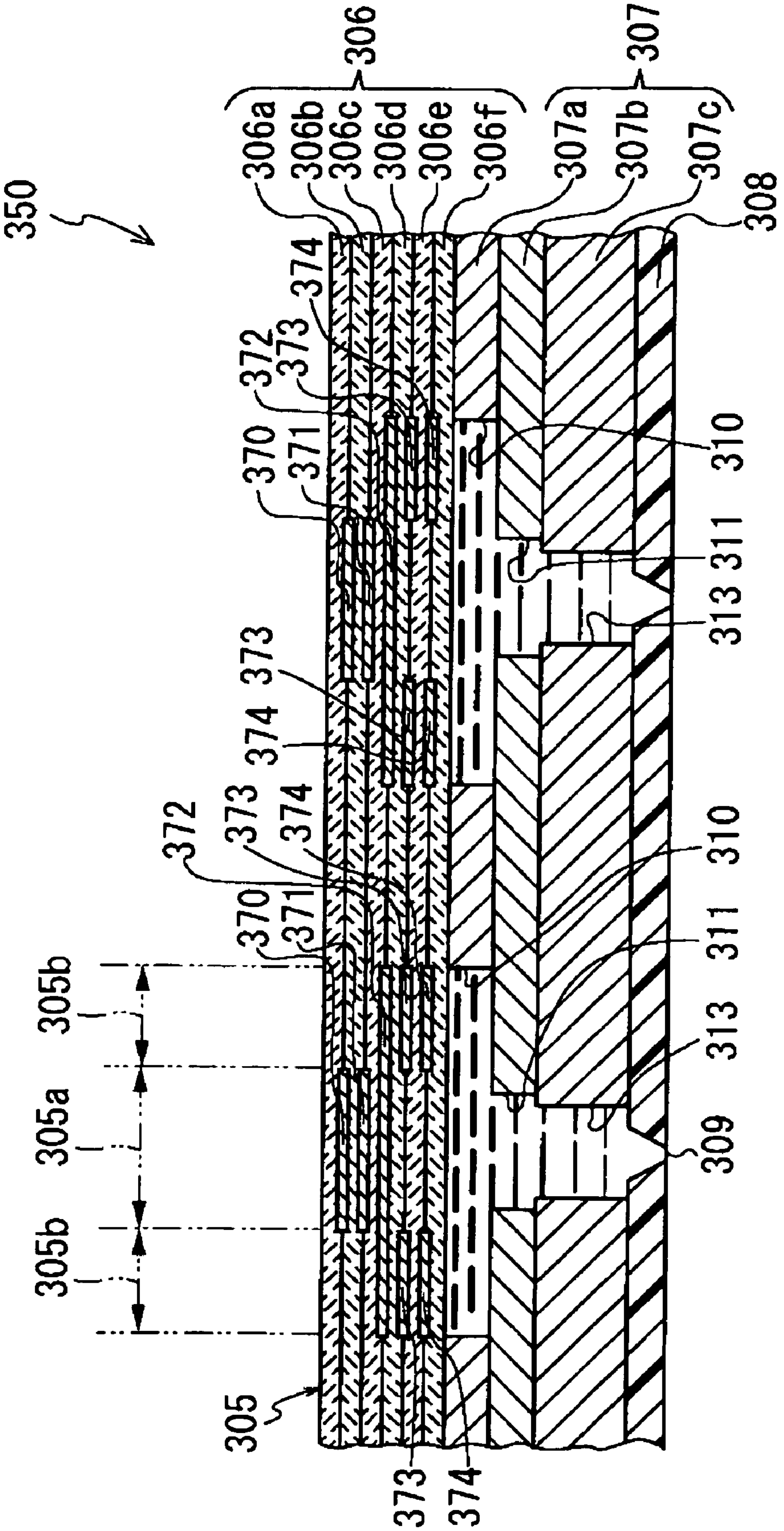

350
306
306a
306b
306c
306d
306e
306f
307
307a
307b
307c
308
374
373
372
371
370
310
311
313
374
373
372
373
374
370
371
310
311
313
309
305b
305a
305b
305
373
374

FIG. 21

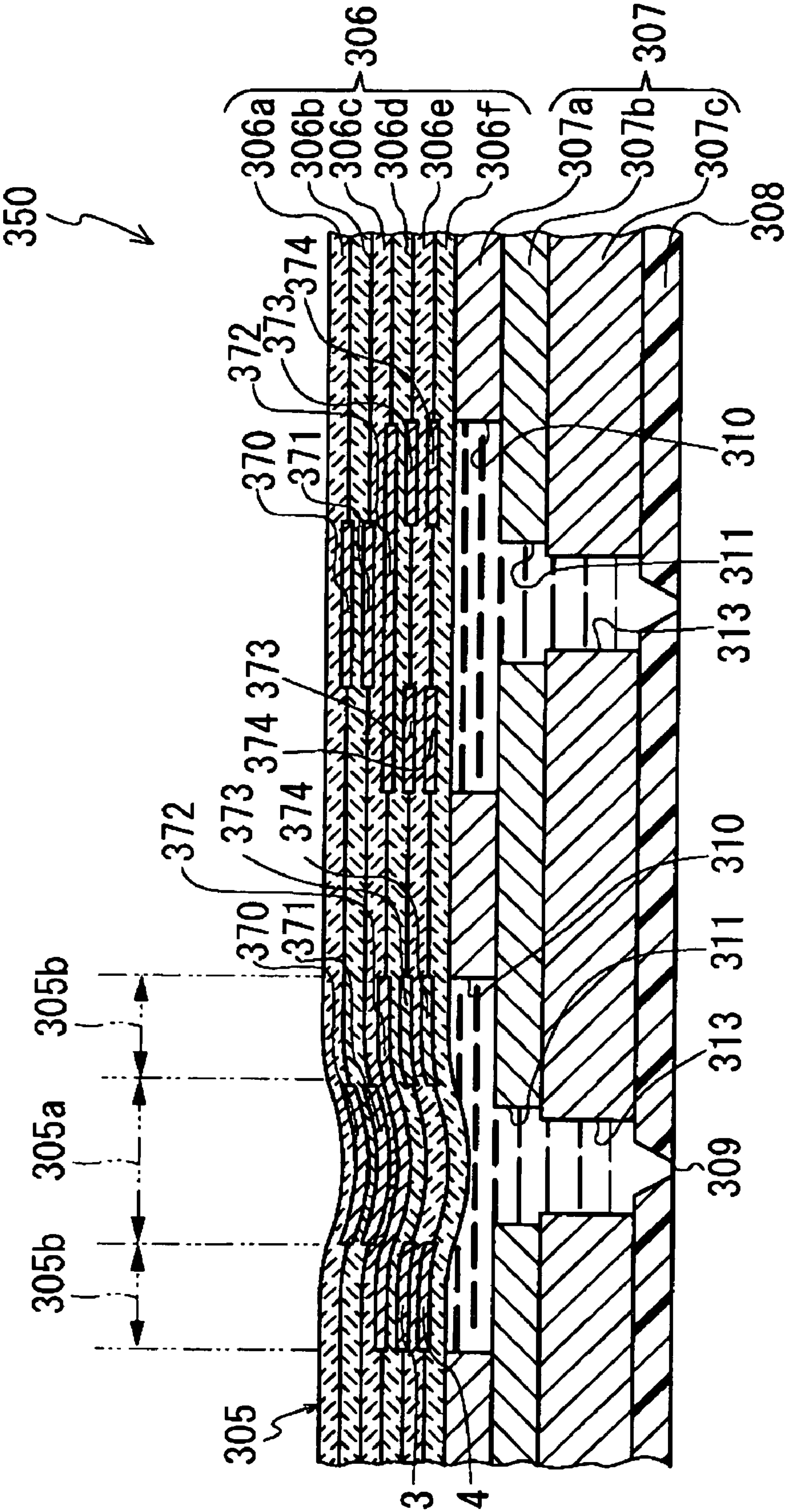

350
306
306a
306b
306c
306d
306e
306f
307
307a
307b
307c
308
370
371
372
373
374
310
311
313
309
305
305a
305b
373
374

FIG. 22

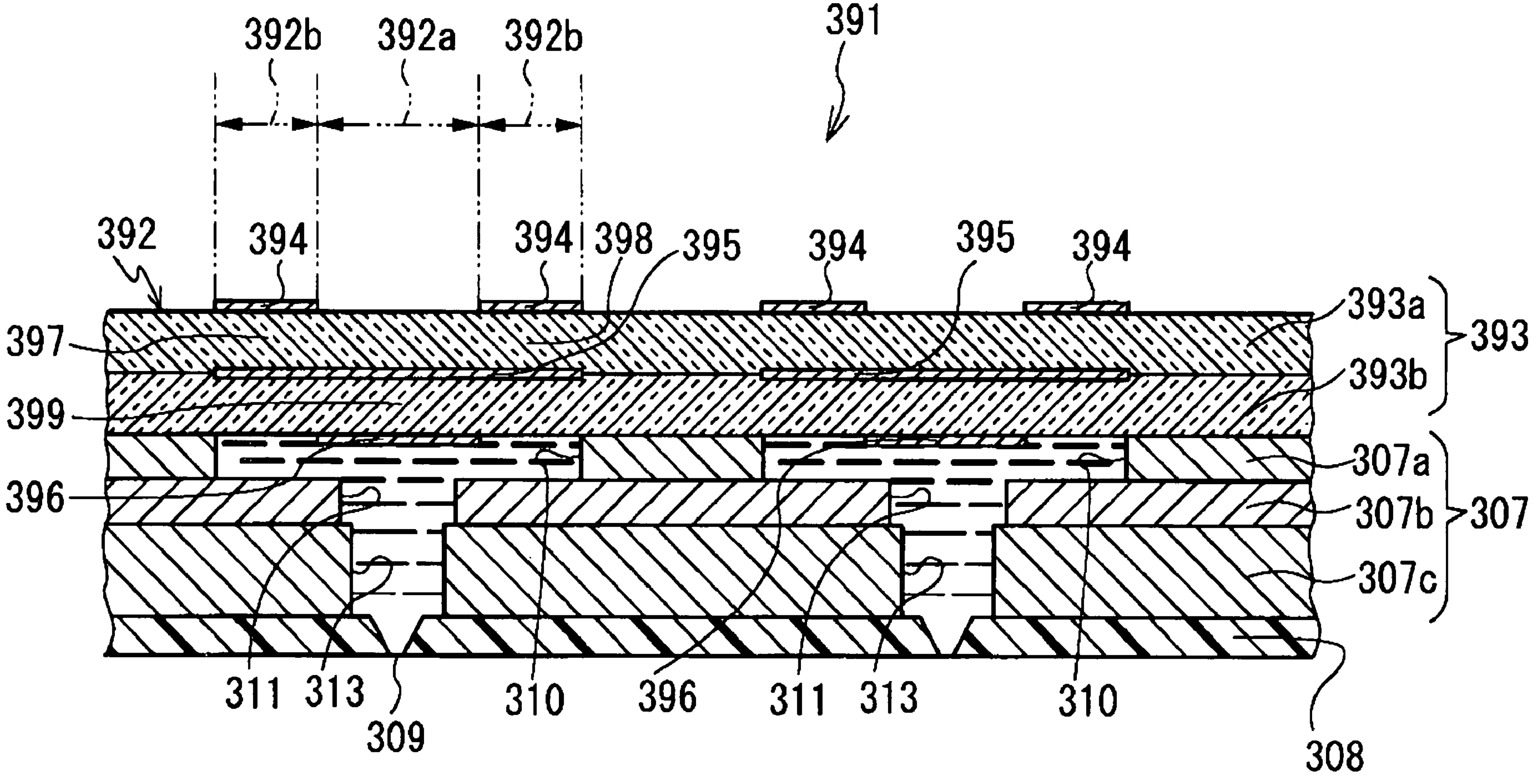

392b
392a
392b
391
392
394
394
398
395
394
395
394
393a
393
397
393b
399
307a
396
307b
307
307c
311
313
309
310
396
311
313
310
308

FIG. 23

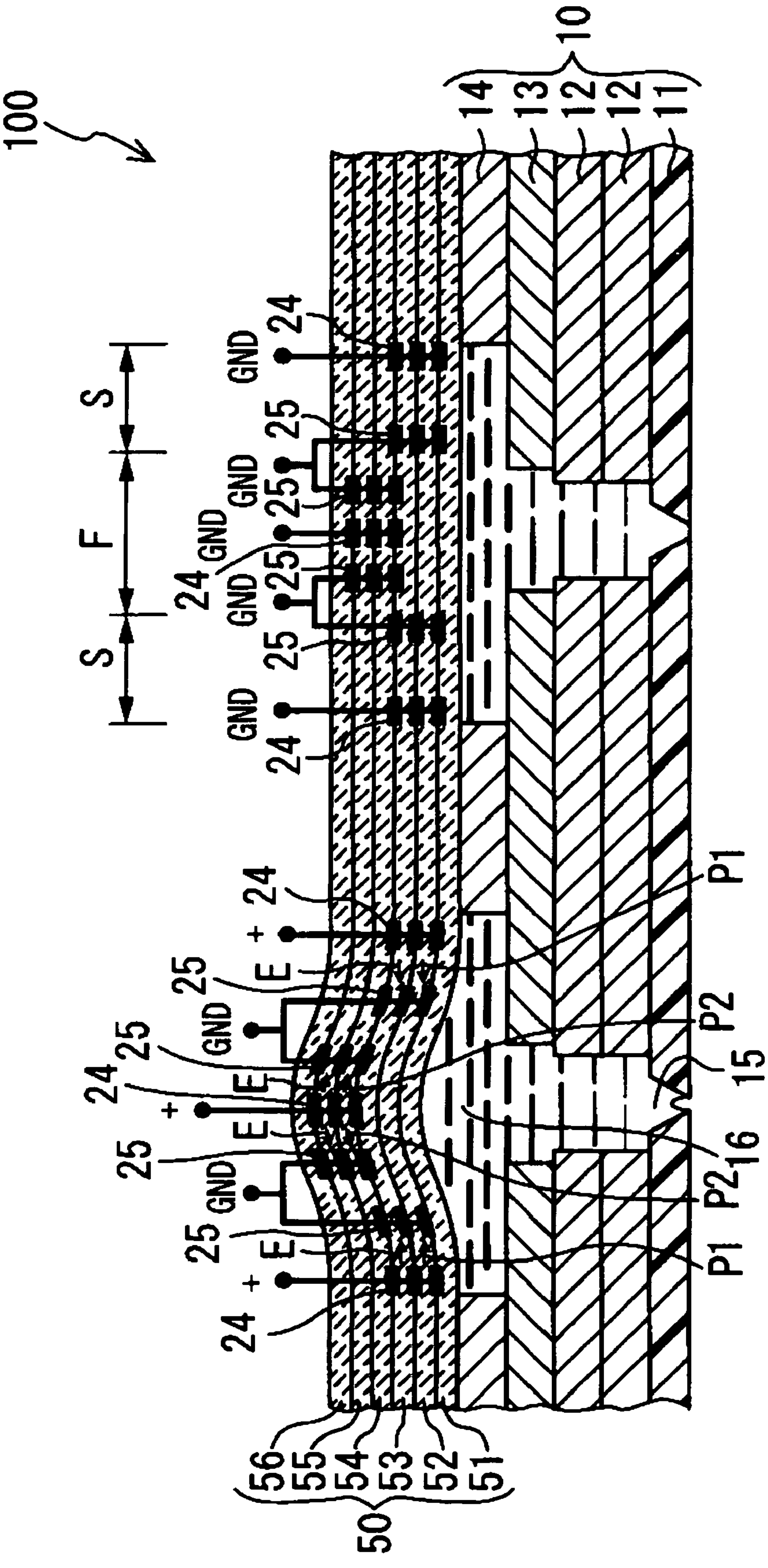

100
10
14
13
12
12
11
S
F
S
GND
24
25
GND
25
GND
GND
25
24
GND
25
GND
24
+
24
E
25
GND
P1
P2
15
25
24
E
E
+
E
16
25
GND
P2
25
E
P1
+
24
56
55
54
53
52
51
50

FIG. 24

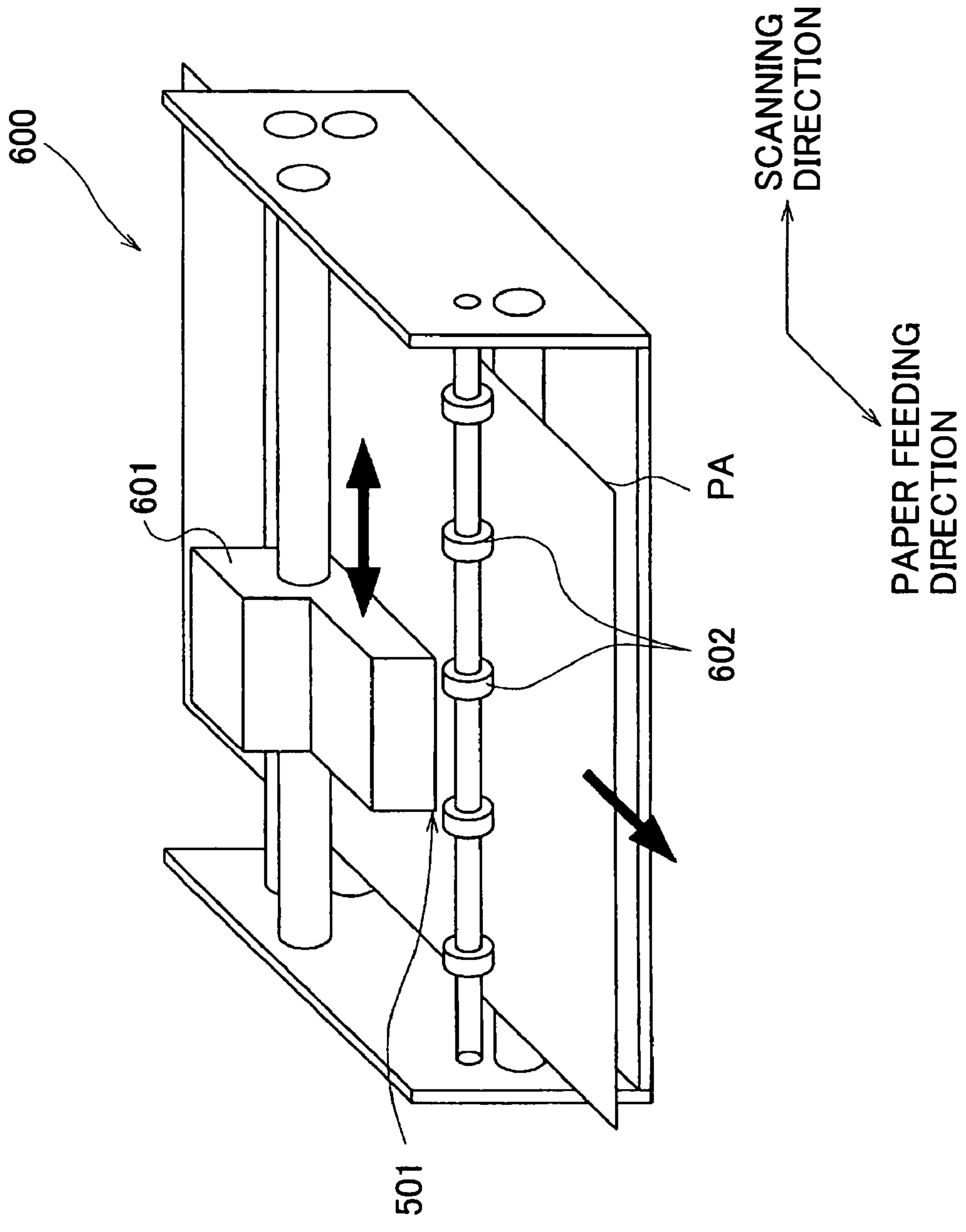

600
601
PA
602
501
SCANNING DIRECTION
PAPER FEEDING DIRECTION

FIG. 25

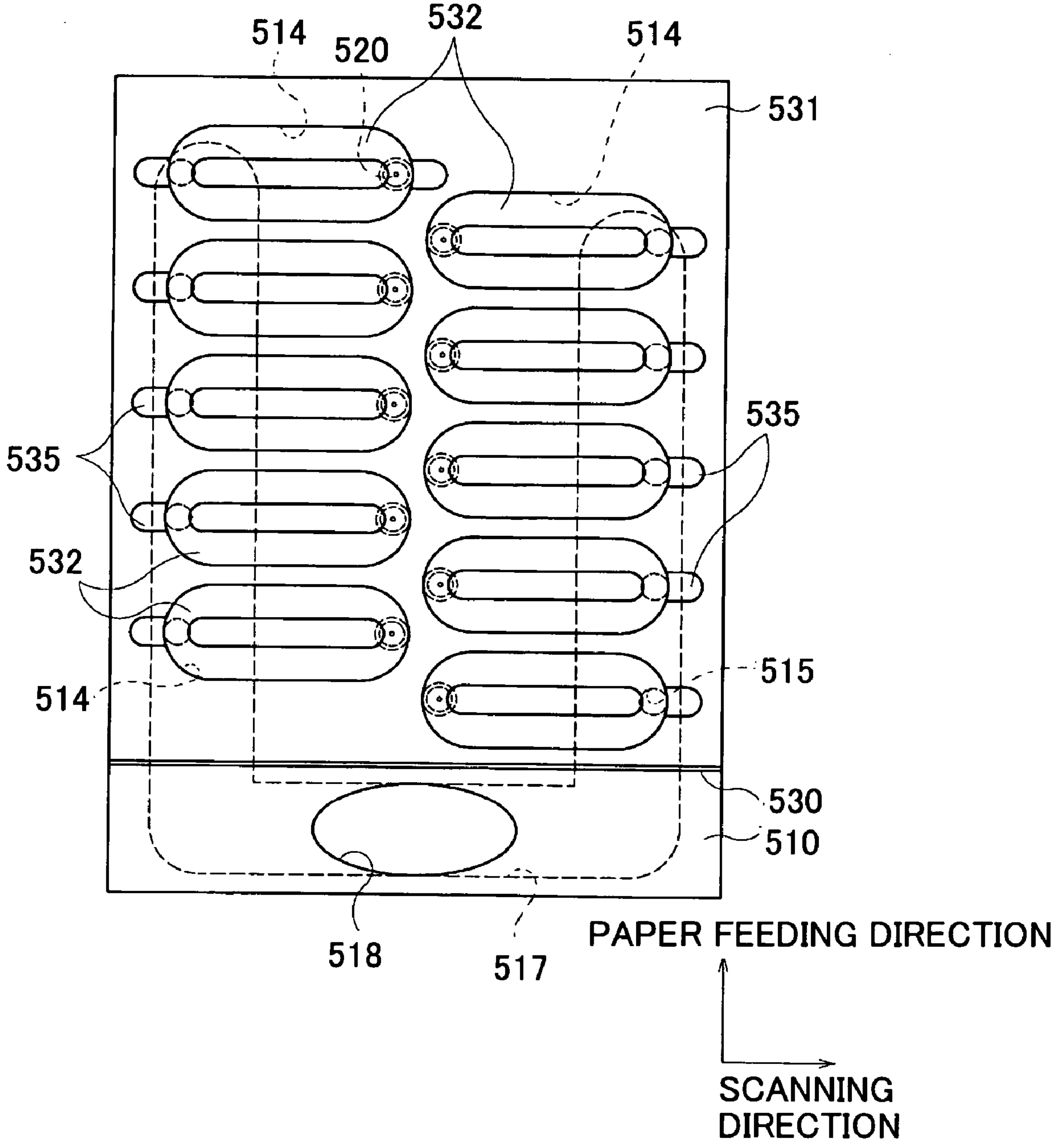

514
520
532
514
531
535
535
532
514
515
530
510
518
517
PAPER FEEDING DIRECTION
SCANNING DIRECTION

FIG. 26

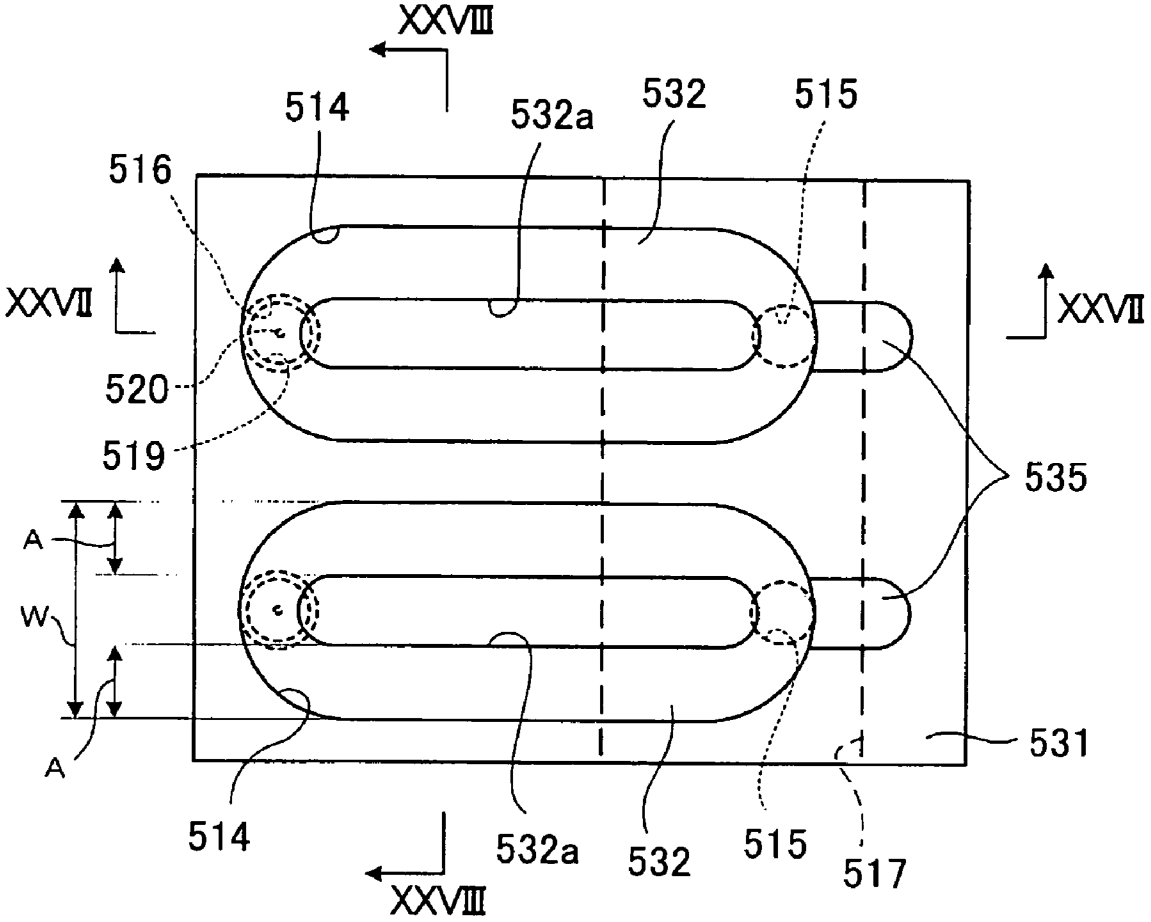

XXVIII
514
532a
532
515
516
XXVII
XXVII
520
519
535
A
W
A
531
514
532a
532
515
517
XXVIII

FIG. 27

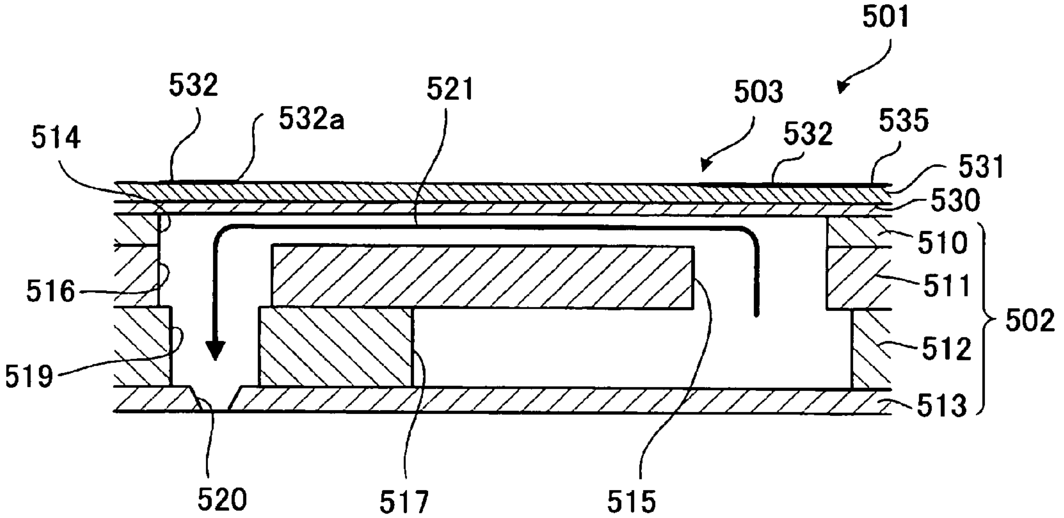

501
503
532
532a
521
532
535
514
531
530
510
511
502
516
512
519
513
520
517
515

FIG. 28

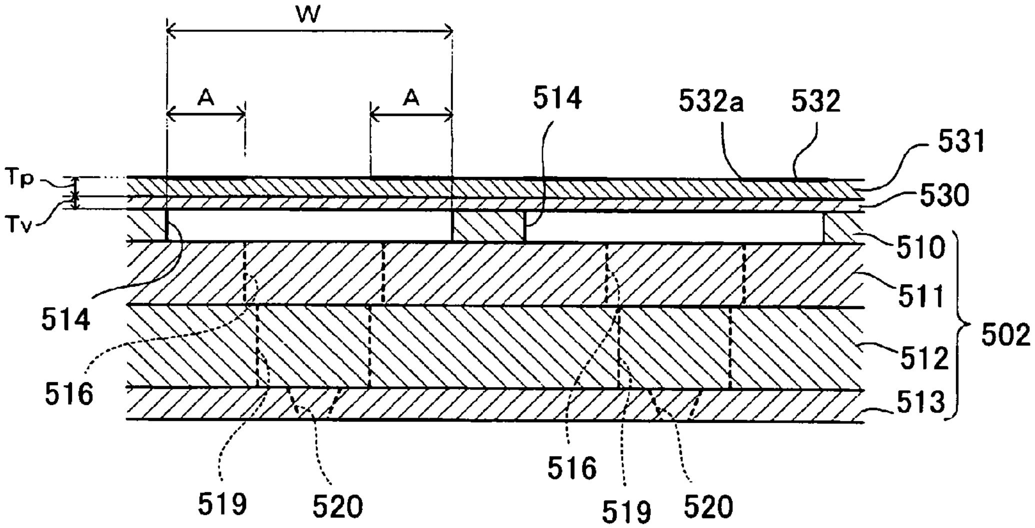

W
A
A
514
532a
532
531
Tp
Tv
530
510
511
502
514
512
516
513
516
519
520
519
520

FIG. 29

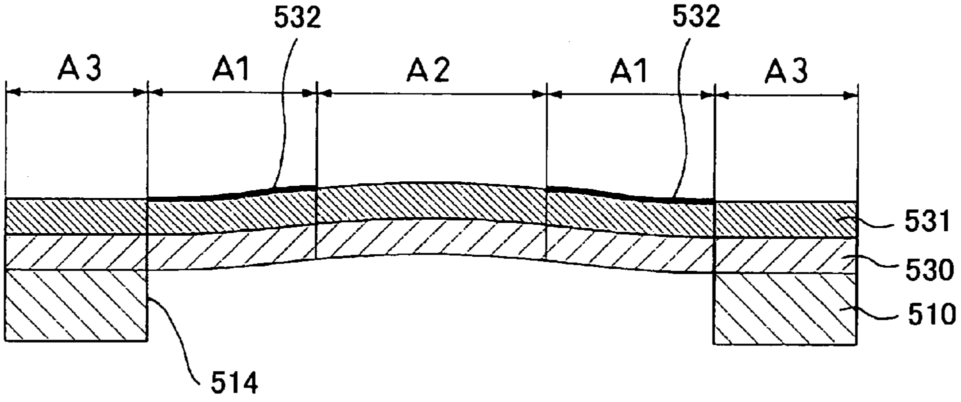

532
532
A3
A1
A2
A1
A3
531
530
510
514

FIG. 30

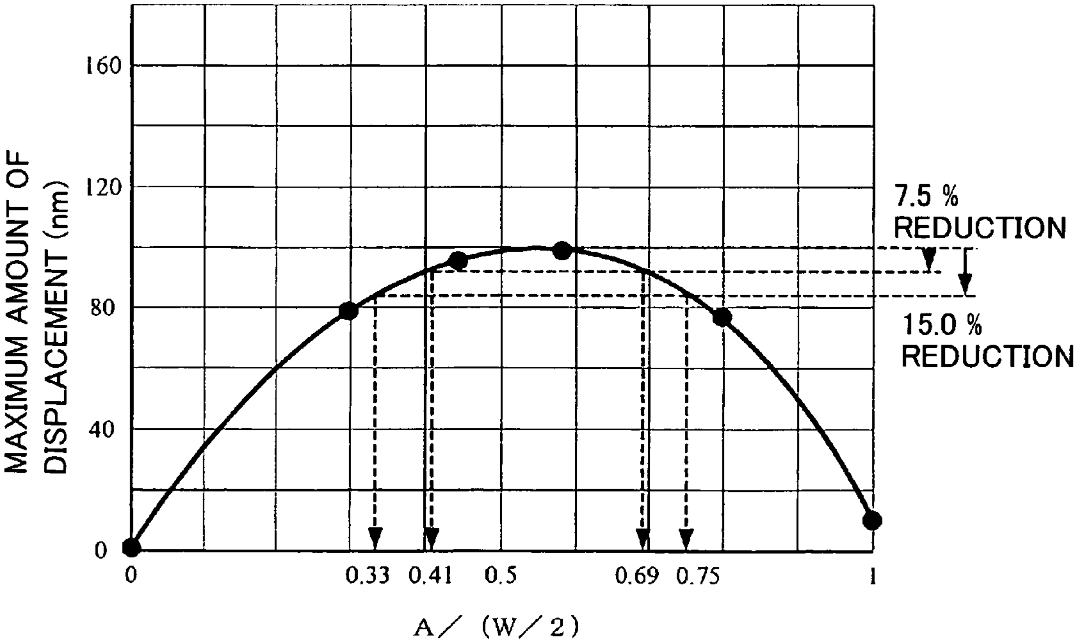

MAXIMUM AMOUNT OF DISPLACEMENT (nm)
160
120
80
40
0
0
0.33
0.41
0.5
0.69
0.75
1
A／(W／2)
7.5 % REDUCTION
15.0 % REDUCTION

FIG. 31

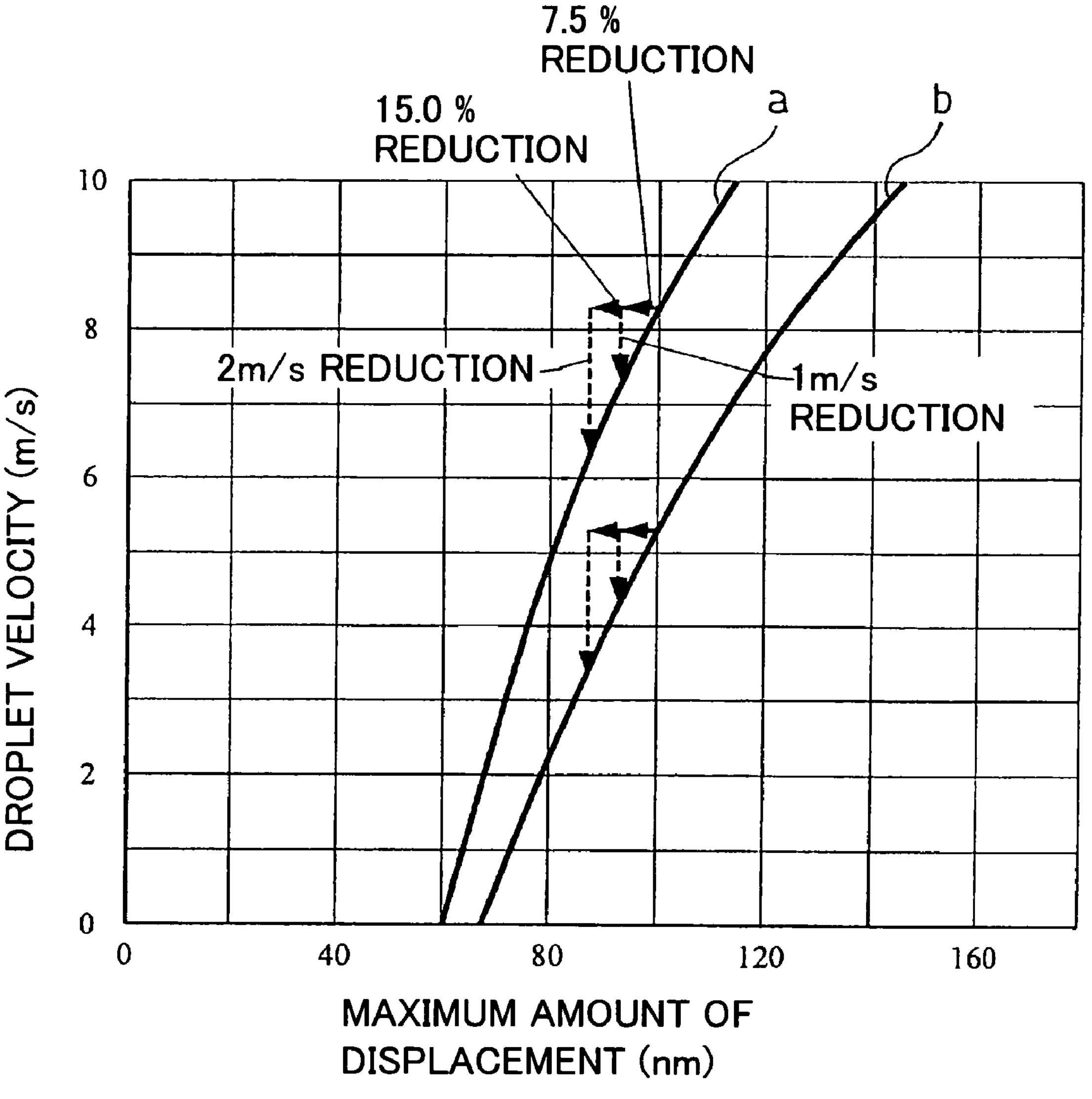

7.5 %
REDUCTION
15.0 %
REDUCTION
a
b
10
8
6
4
2
0
2m/s REDUCTION
1m/s
REDUCTION
DROPLET VELOCITY (m/s)
0
40
80
120
160
MAXIMUM AMOUNT OF
DISPLACEMENT (nm)

FIG. 32A

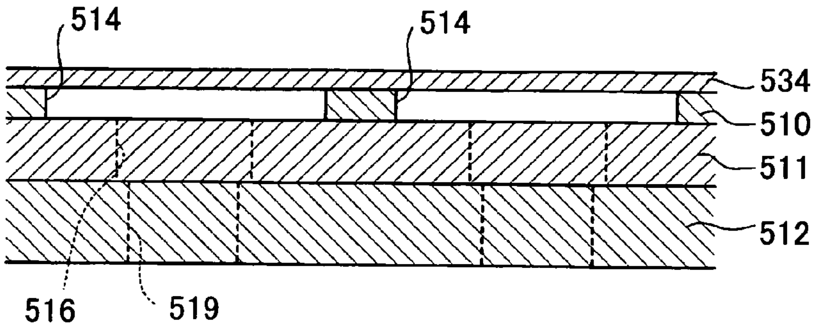


FIG. 32B

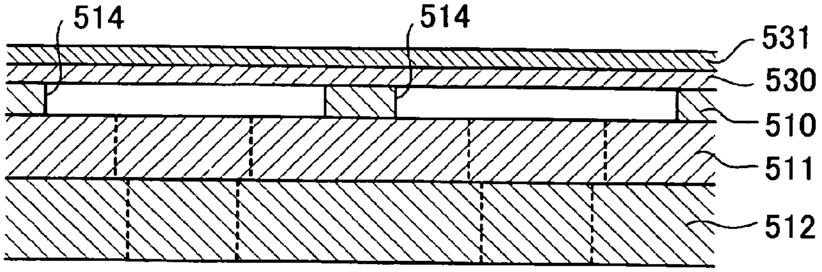


FIG. 32C

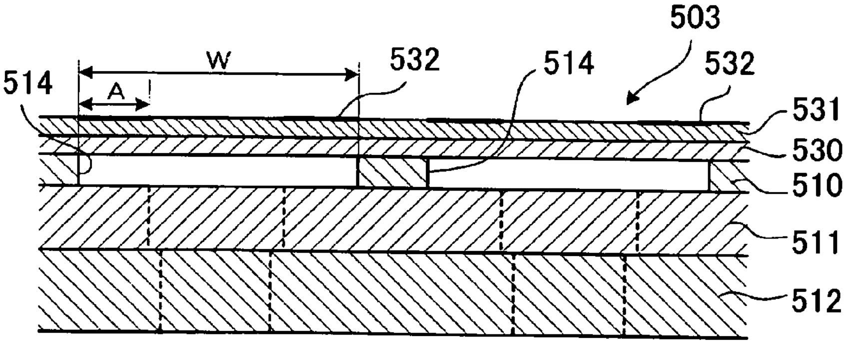


FIG. 32D

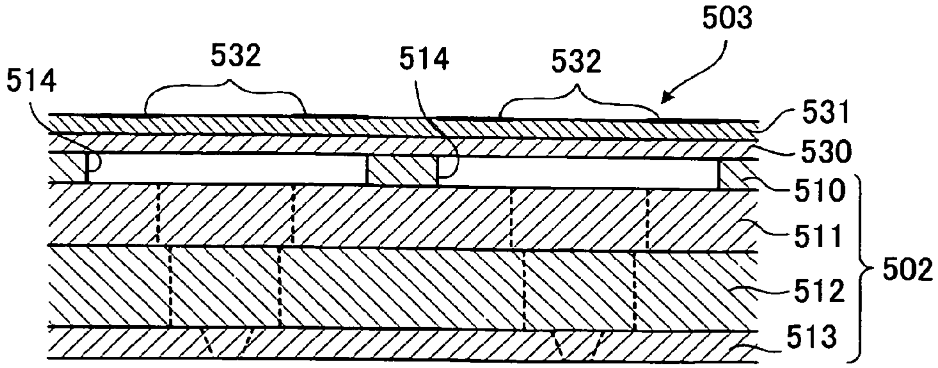


FIG. 33

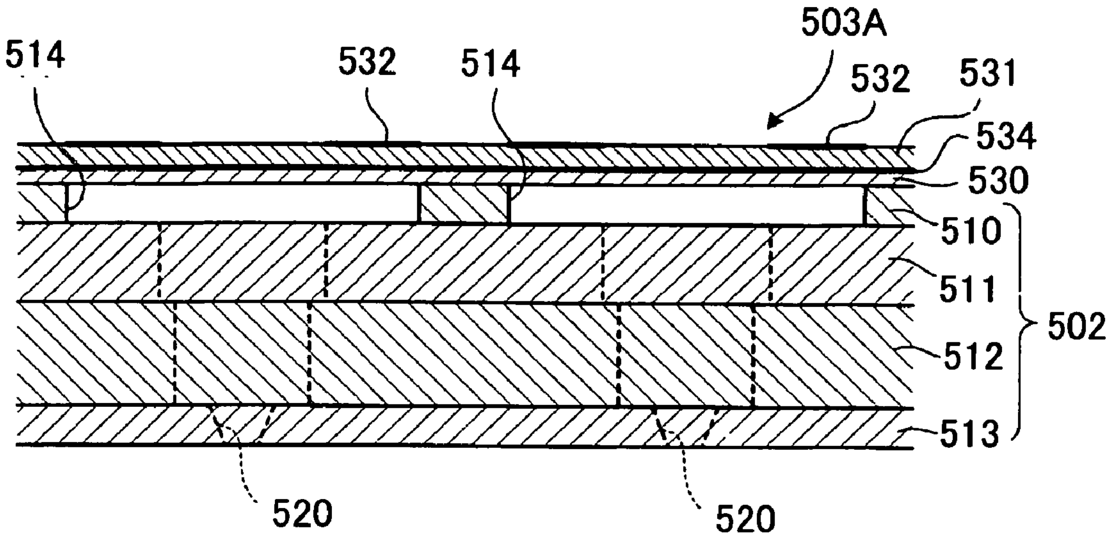

503A
514
532
514
532
531
534
530
510
511
502
512
513
520
520

FIG. 34

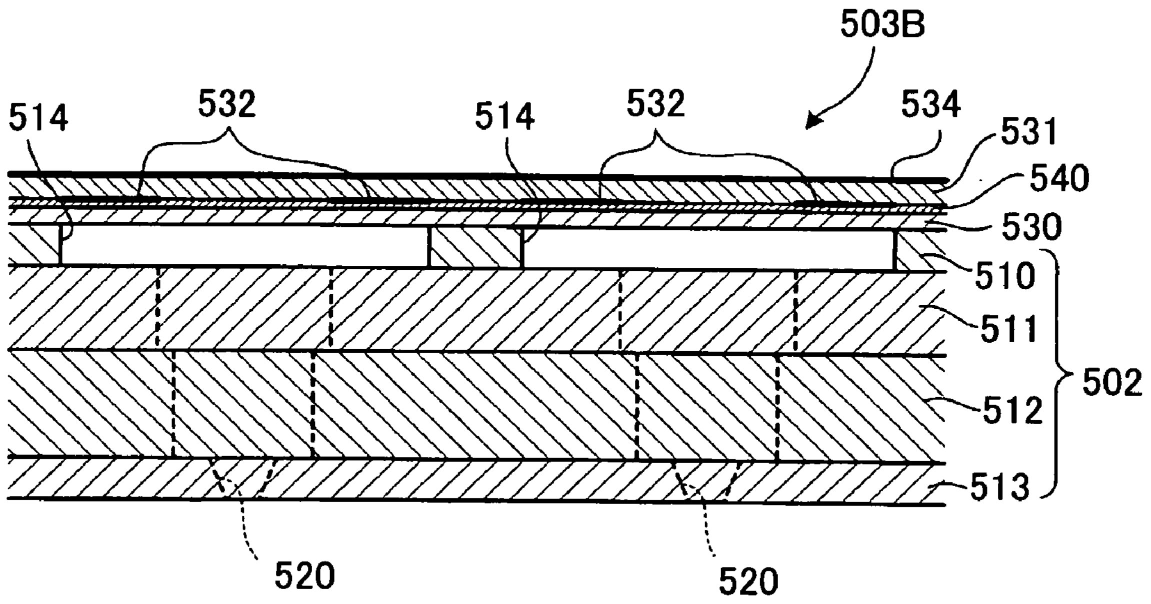

503B
514
532
514
532
534
531
540
530
510
511
502
512
513
520
520

FIG. 35

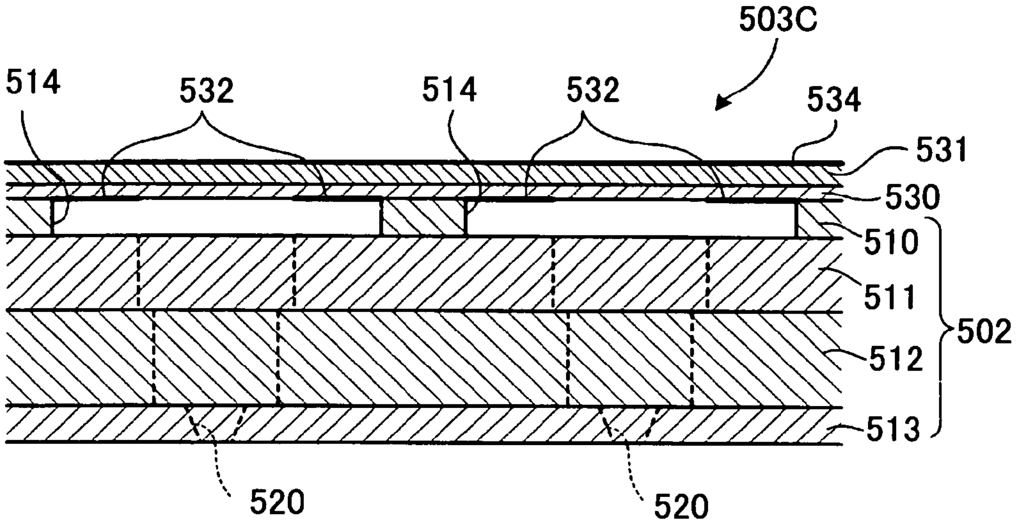

503C
514
532
514
532
534
531
530
510
511
502
512
513
520
520

FIG. 36

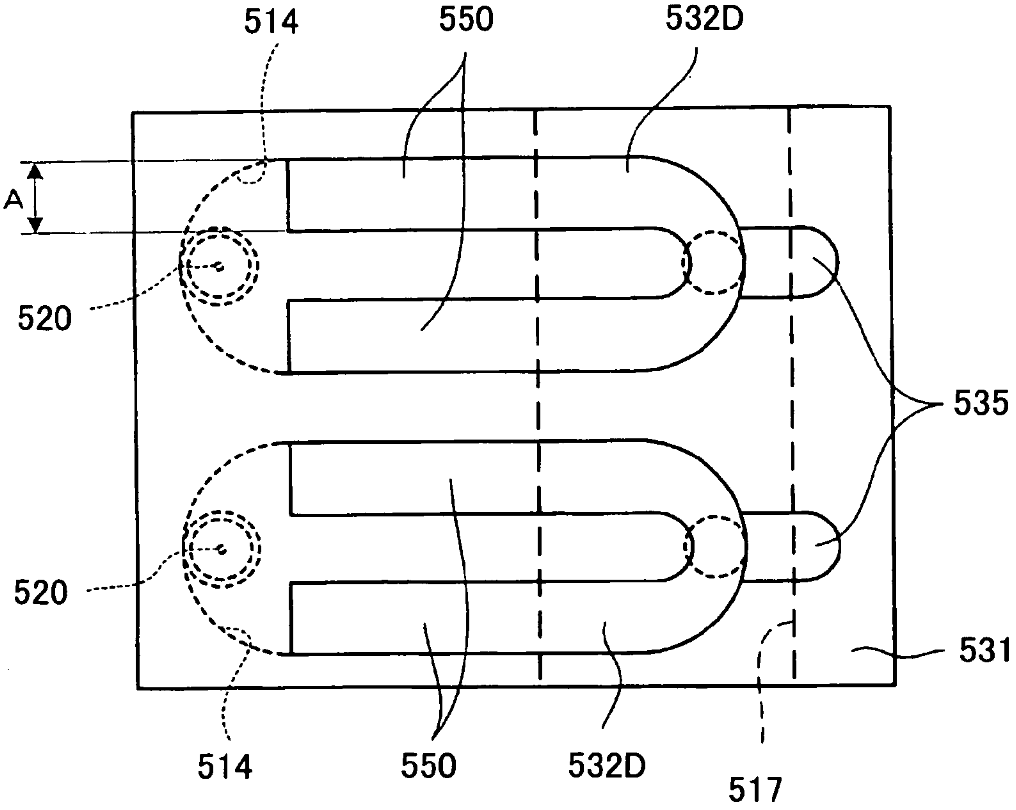

514
550
532D
A
520
535
520
531
514
550
532D
517

FIG. 37

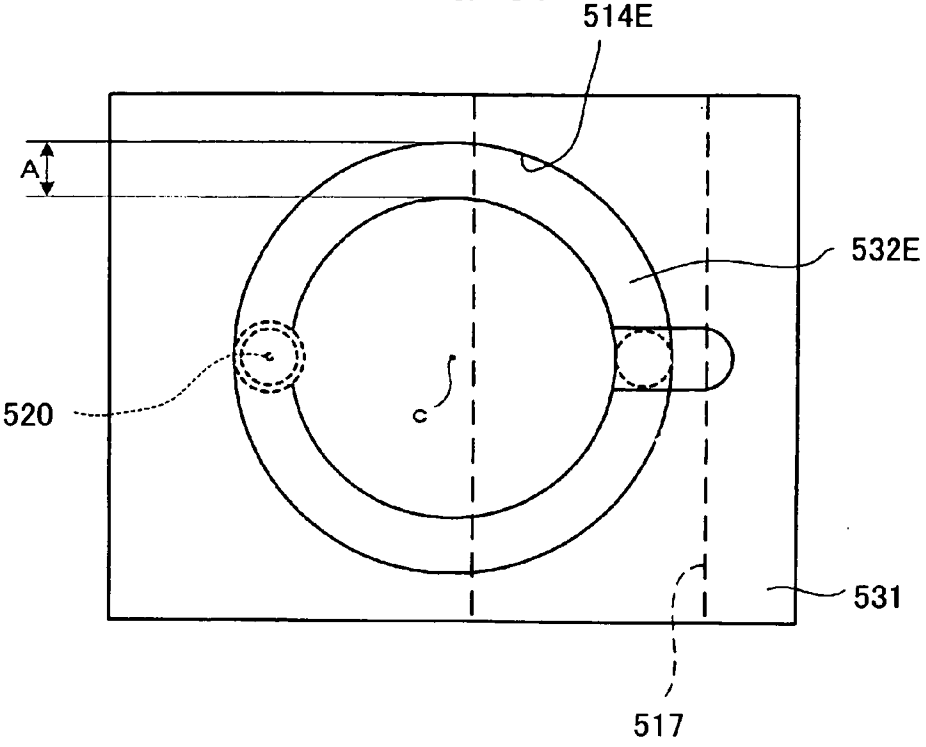

514E
A
532E
520
C
531
517

FIG. 38

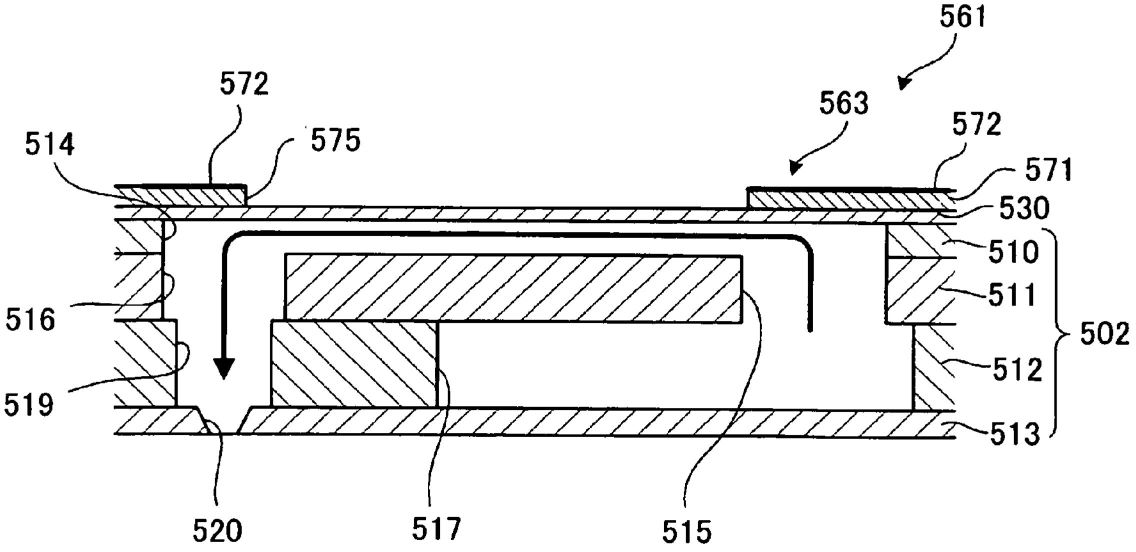

561
563
572
575
514
572
571
530
510
511
502
516
512
519
513
520
517
515

FIG. 39

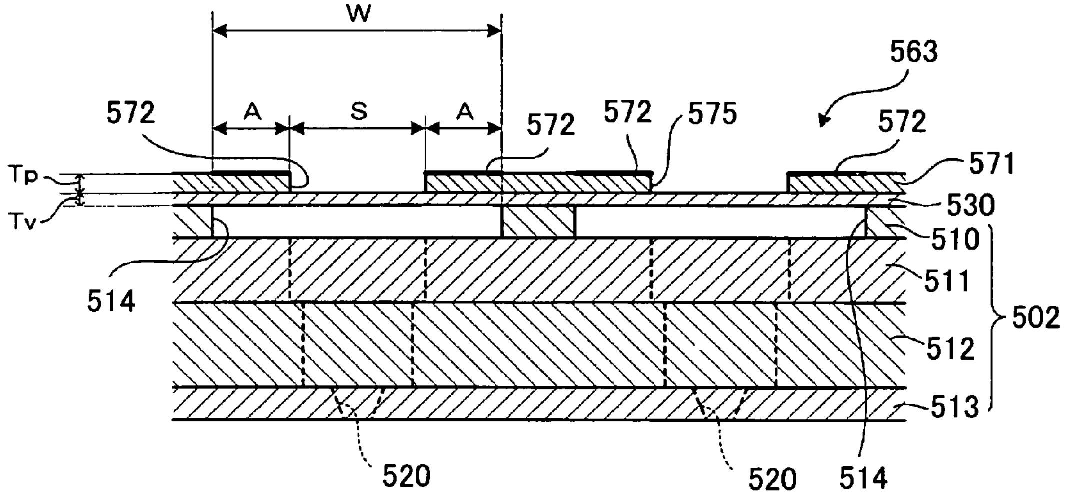

W
A
S
A
563
572
572
572
575
572
571
530
510
511
502
512
513
Tp
Tv
514
520
520
514

FIG. 40

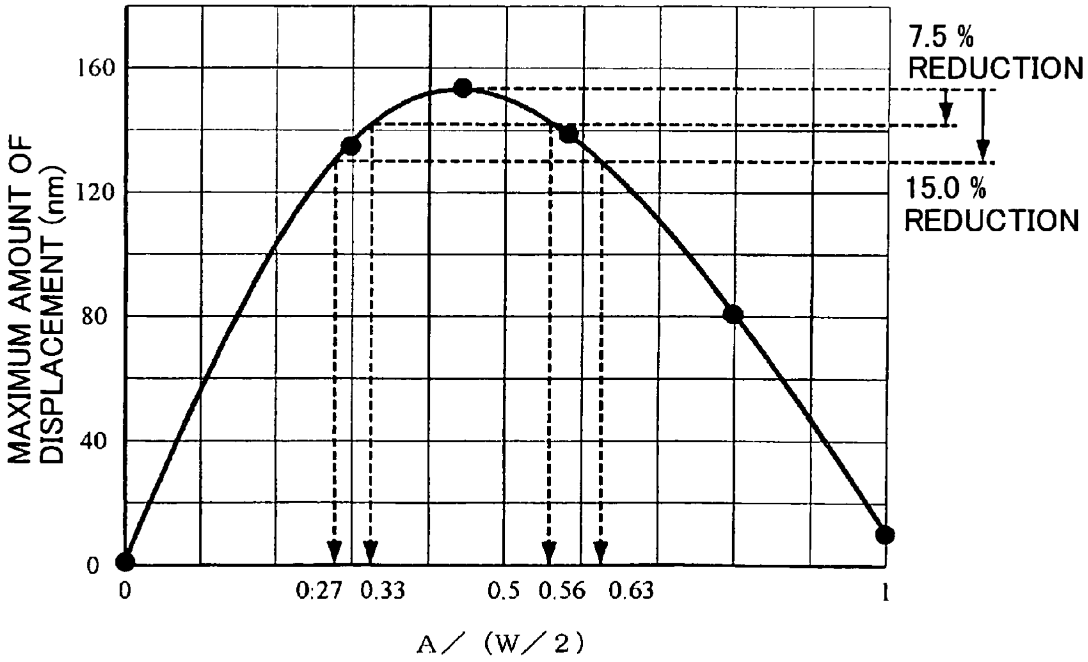

MAXIMUM AMOUNT OF DISPLACEMENT (nm)
160
120
80
40
0
0
0.27
0.33
0.5
0.56
0.63
1
A／（W／2）
7.5 % REDUCTION
15.0 % REDUCTION

FIG. 41

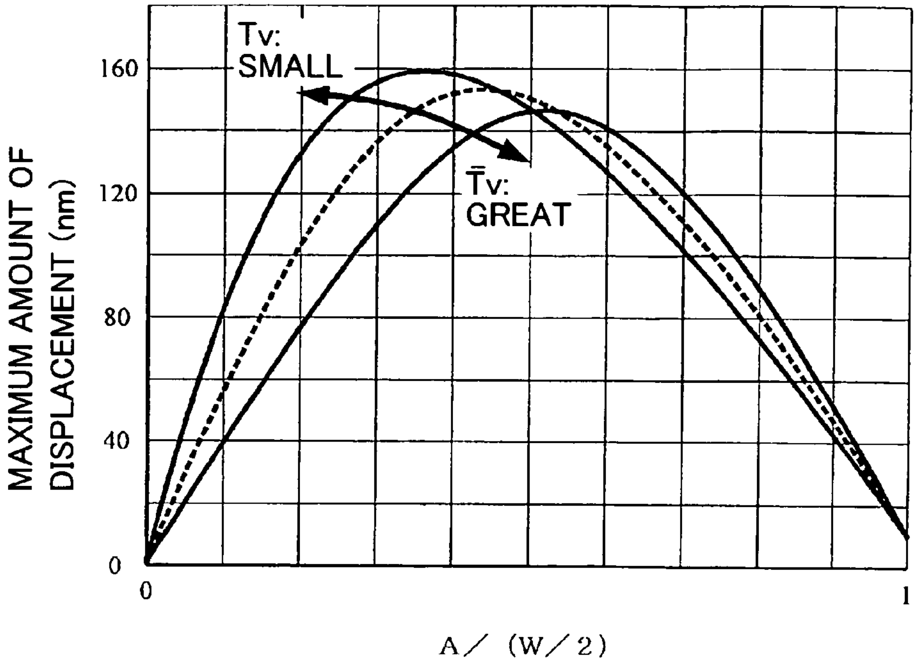

Tv:
SMALL
Tv:
GREAT
160
120
80
40
0
0
1
MAXIMUM AMOUNT OF
DISPLACEMENT (nm)
A／ (W／2)

FIG. 42

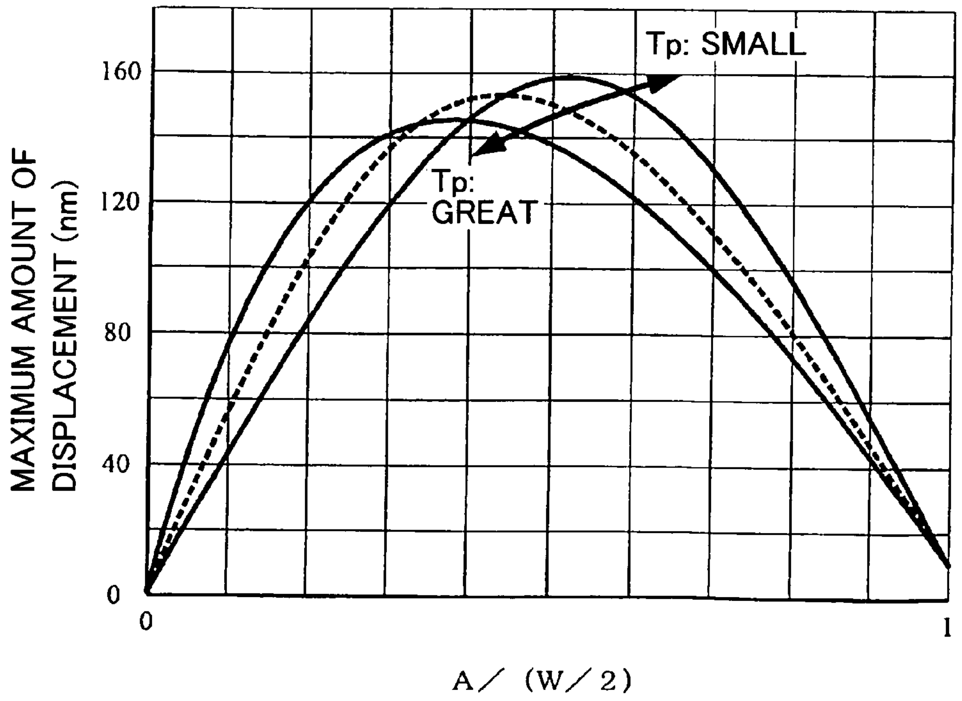

Tp: SMALL
Tp:
GREAT
160
120
80
40
0
0
1
MAXIMUM AMOUNT OF
DISPLACEMENT (nm)
A／ (W／2)

FIG. 43

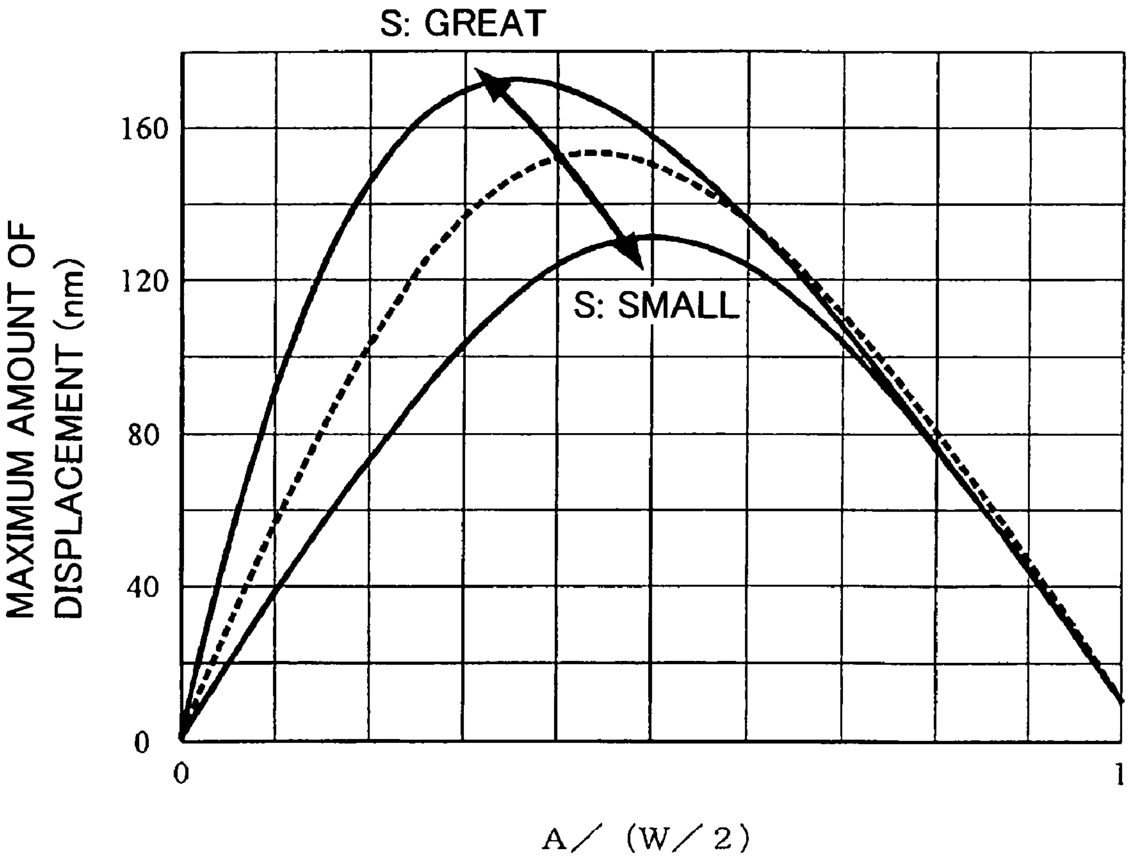

S: GREAT
S: SMALL
MAXIMUM AMOUNT OF DISPLACEMENT (nm)
160
120
80
40
0
0
1
A／ (W／2)

FIG. 44A

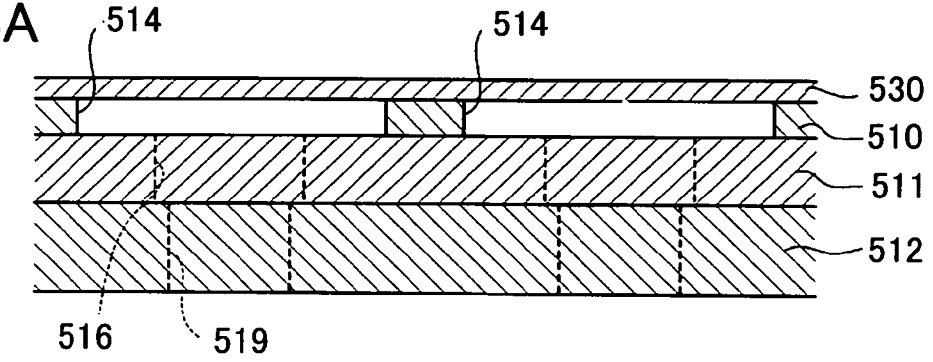


FIG. 44B

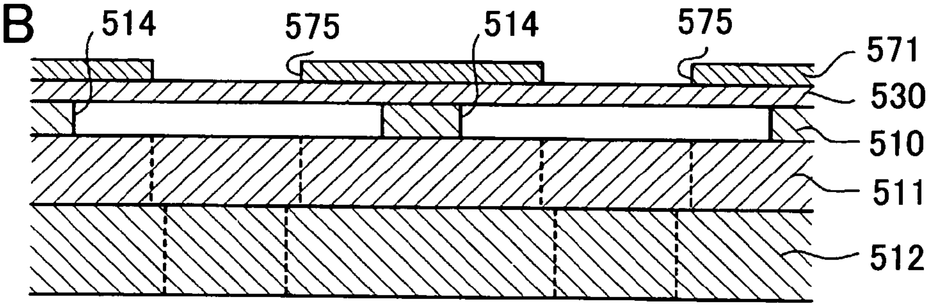


FIG. 44C

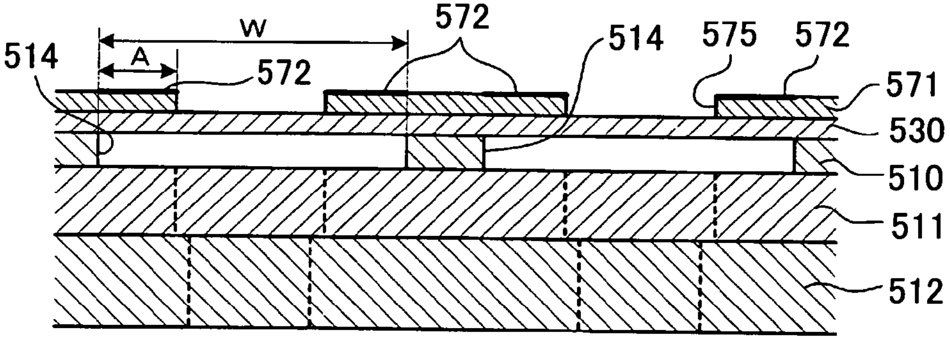


FIG. 44D

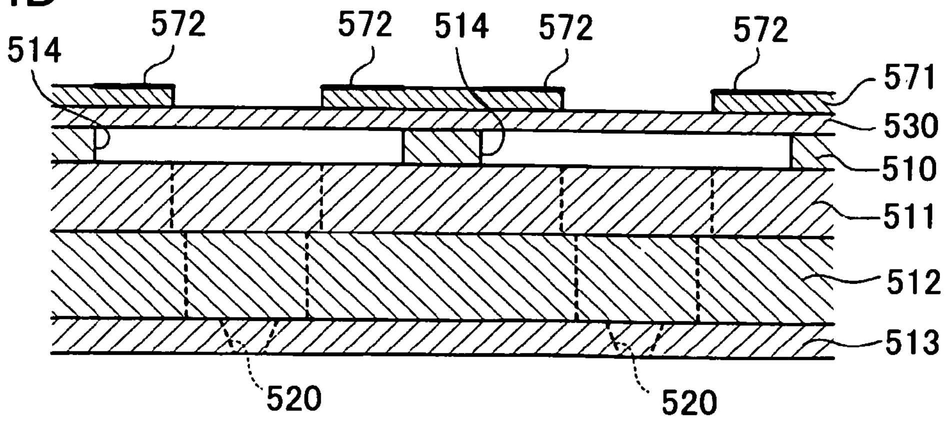


FIG. 45A

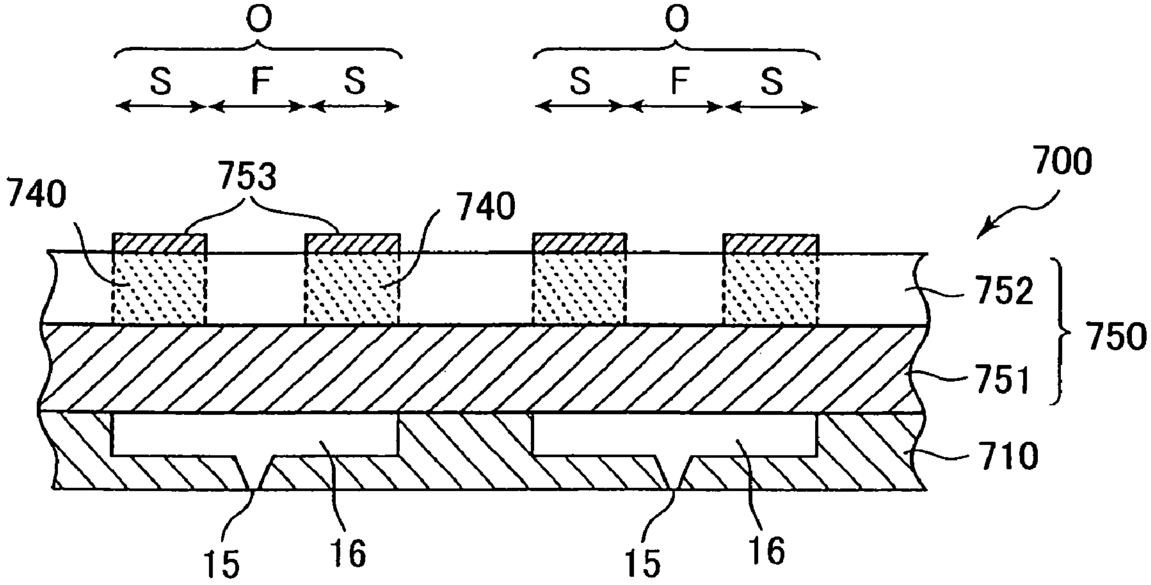


FIG. 45B

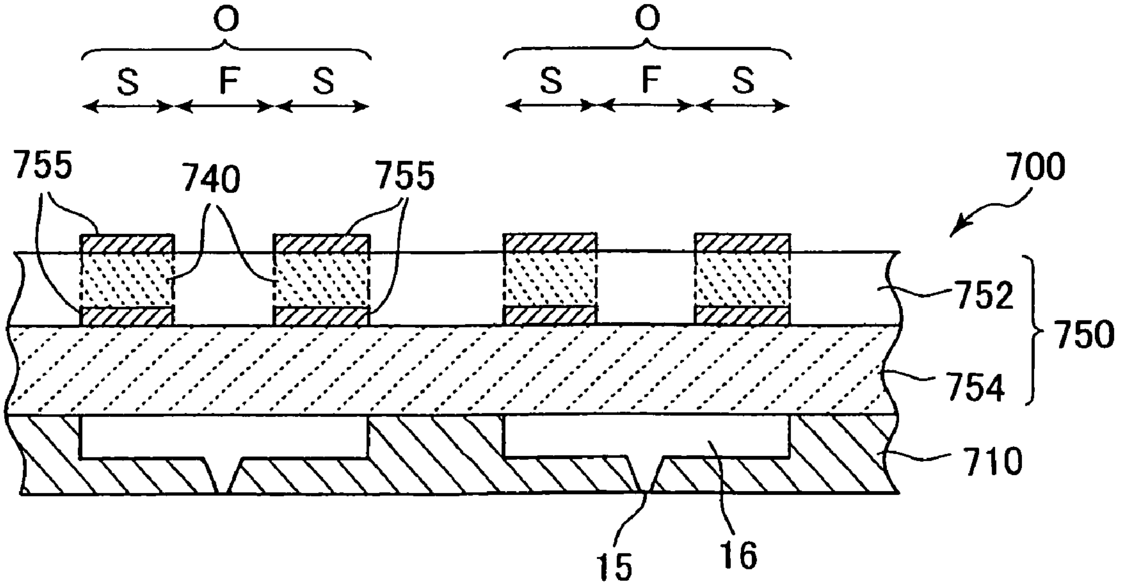


FIG. 46A

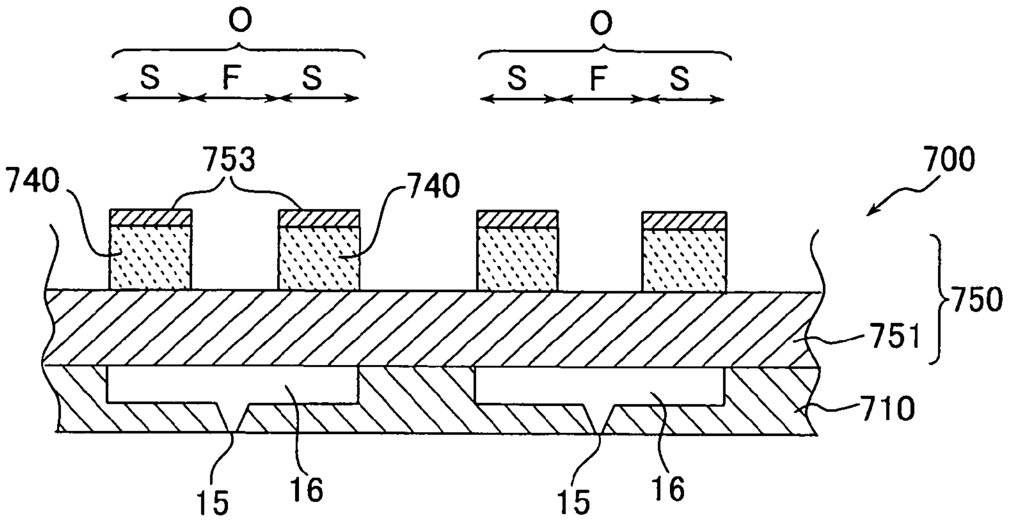


FIG. 46B

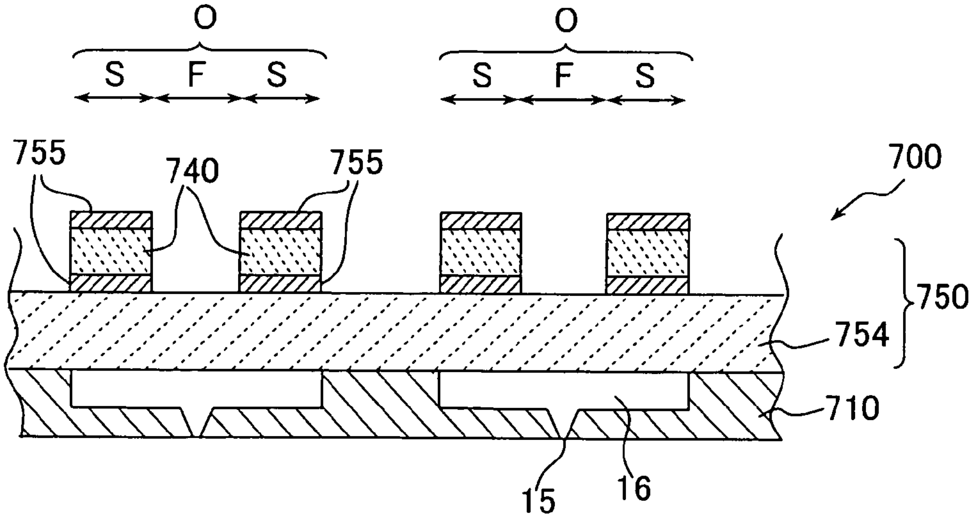


FIG. 47

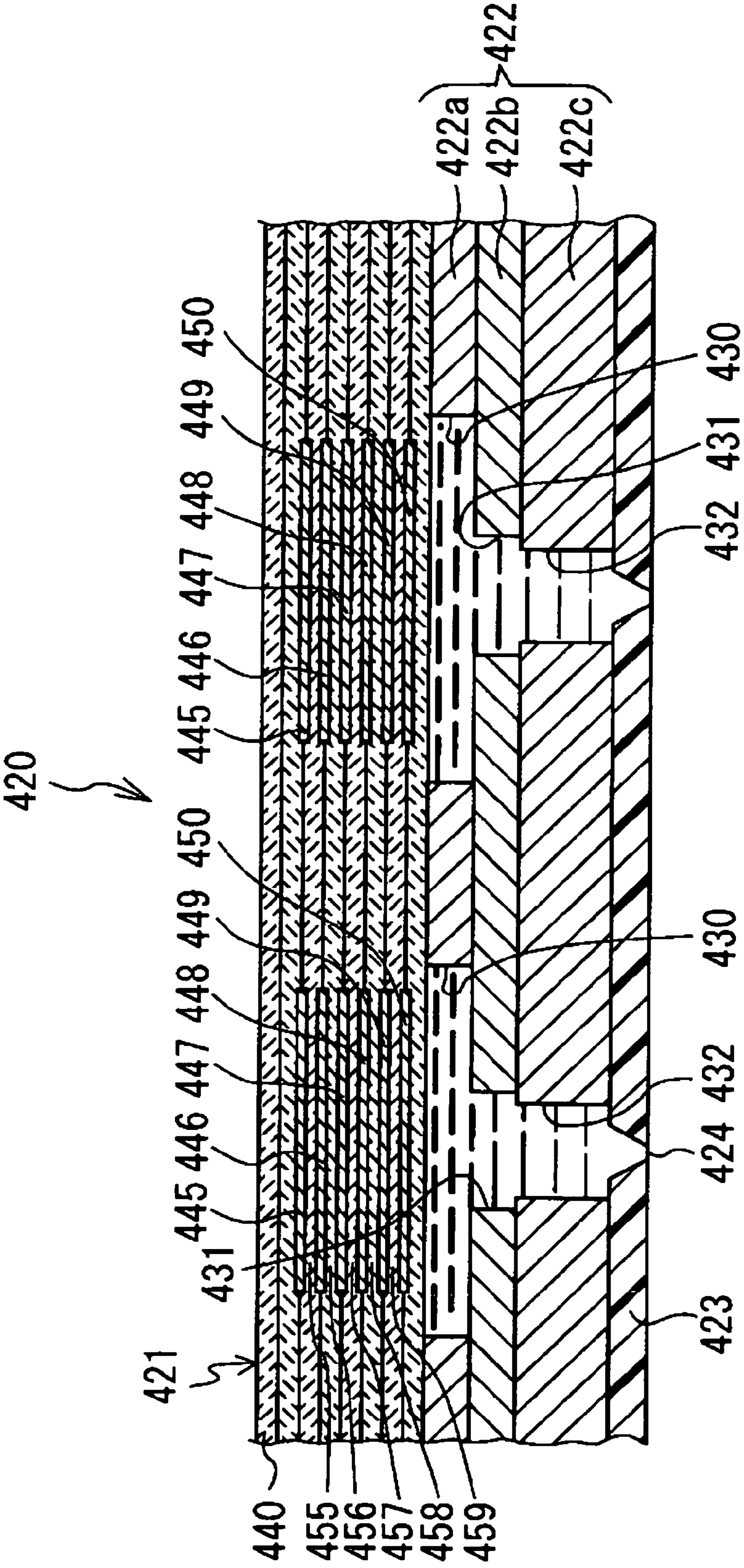
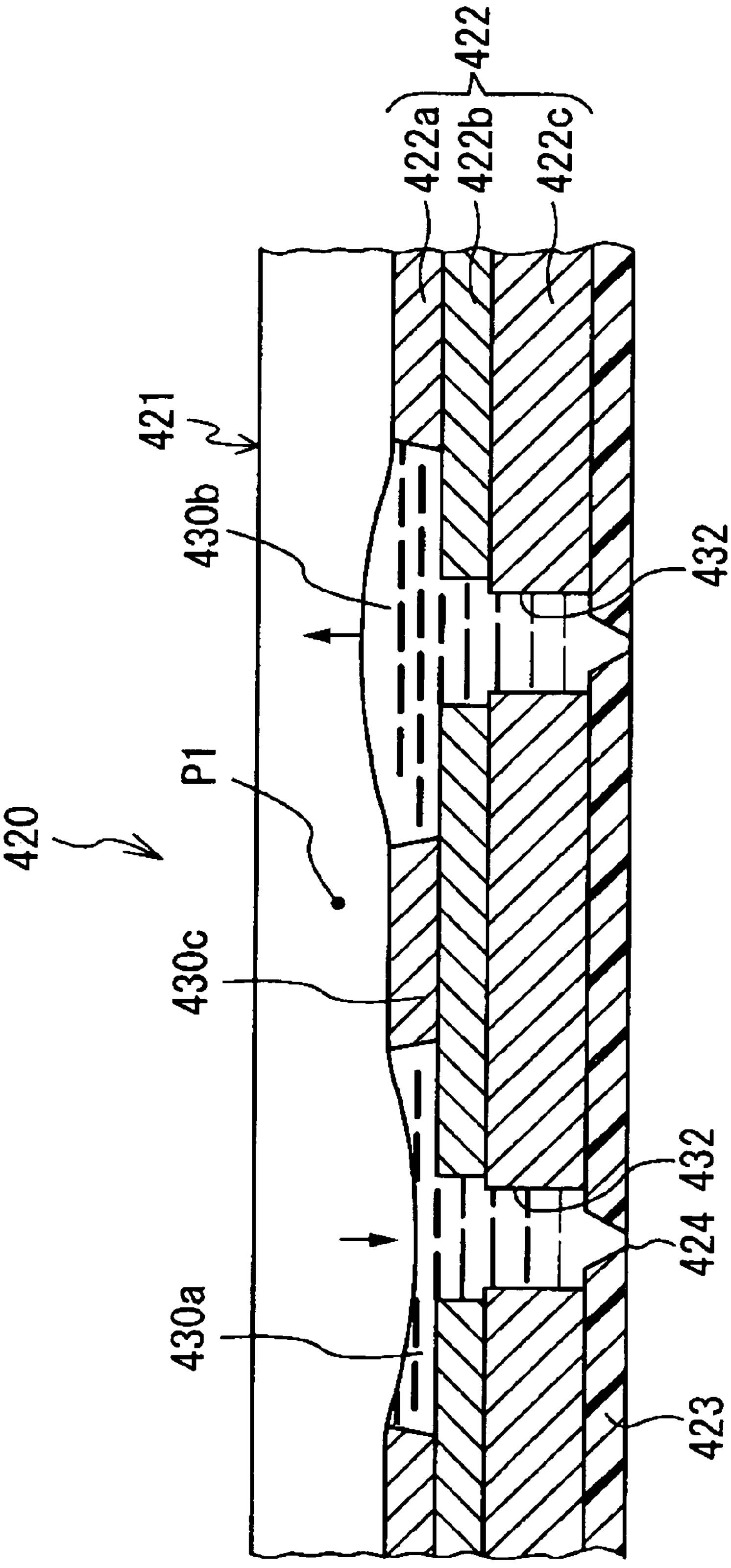

420
421
422
422a
422b
422c
423
424
430
431
432
440
445
446
447
448
449
450
455
456
457
458
459

FIG. 48



LIQUID TRANSPORTING APPARATUS AND METHOD FOR PRODUCING LIQUID TRANSPORTING APPARATUS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a Continuation-In-Part Application of U.S. application Ser. No. 10/310,750 filed on Dec. 5, 2002 now U.S. Pat. No. 6,971,738 claiming the priority of Japanese patent Applications No. 2001-372104 filed on Dec. 6, 2001; No. 2002-132195 filed on May 8, 2002; and No. 2002-284304 filed on Sep. 27, 2002.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid transporting apparatus which transport a liquid and a method for producing a liquid transporting apparatus.

2. Description of Related Art

As an example of conventional recording apparatus which performs recording on a recording medium such as paper, an ink-jet printer provided with an ink-jet head is known (for example, see Patent Document 1).

[Patent Document 1] Japanese Patent Publication No. 3128857

As shown in FIG. **47**, the ink-jet head **420** is constructed of a stack in which an actuator plate **421** driven by a drive voltage generated in a driving circuit (not shown), a cavity plate **422** forming an ink channel for flowing an ink threrethrough, and a nozzle plate **423** provided with nozzles **424** from which the ink is ejected are stacked in layers such that the piezoelectric actuator plate **421**, the cavity plate **422** and the nozzle plate **423** are positioned at upper, middle and lower portions in the stack respectively. The cavity plate **422** is constructed of three layers **422***a* to **422***c* stacked on top of the each other. With the etching or the like, pressure chambers **430** for accommodating the ink are formed in the upper layer **422***a*, a manifold (now shown) for supplying the ink to the pressure chambers and communicating holes **432** are formed in the lower layer **422***c*, and communicating holes (now shown) for communicating the pressure chambers **430** and the manifold and communicating holes **431** for communicating the pressure chambers **430** and the nozzles **424** are formed in the middle layer **422***b*.

The piezoelectric actuator plate **421** is formed of a piezoelectric ceramic material made of a lead zirconate titanate (PZT) of ceramic material, and is provided with a plurality of piezoelectric ceramics layers **440** having the piezoelectric effect and a plurality of inner-side electrodes **445**, **446**, **447**, **448**, **449**, **450** interposed between the ceramic layers. Each of the inner-side electrodes **445** to **450** is arranged in a portion corresponding to the central portion of one of the pressure chambers **430**. The portions of the piezoelectric ceramic layers **440**, sandwiched between the inner-side electrodes **445** to **450**, serve as active portions **445**, **456**, **457**, **458**, **459** each of which extends in a direction in which the layers are stacked when a voltage is applied to the inner-side electrodes **445** to **450**. As shown in FIG. **48**, when a voltage is applied to the inner-side electrodes **445** to **450**, in the piezoelectric actuator plate **421**, which correspond to an arbitrary pressure chamber **430***a*, an electric field parallel to the polarization direction is generated in the active portion **455** to **459**, then the active portions **455** to **459** extend in the direction in which the layers are stacked so that pressure is applied to the ink in the pressure chamber **430** for ejecting the ink.

However, as shown in FIG. **48**, in the conventional technique as described above, the electrodes **445** to **450** are formed to substantially match the shape of the pressure chamber **430** in a plan view and the electrodes **455** to **450** are stacked on top of each other. Accordingly, there is an increase in the surface area of the portions of the piezoelectric ceramic layers **440** disposed between the electrodes **445** to **450**, which give rise to problems such that a capacitance is increased, a larger electric current is required in order to rapidly drive the piezoelectric actuator, which in turn decreases the energy efficiency in the piezoelectric actuator.

In addition, when the active portions **455** to **459** deform to project downwardly toward a certain pressure chamber **430***a* for performing the ejection of the ink, the downward deformation of the active portions **445** to **459** produces an opposite reaction, which in turn causes a portion of the piezoelectric actuator plate **421** disposed above another pressure chamber **430***a* adjacent to the certain pressure chamber **430***a* to bend to project upwardly, with a portion above a partition wall **430***c* between these pressure chambers **430** (**430***a* and **430***b*) functioning as a fulcrum **P1**. In addition, the opposite reaction applies force to the partition wall **430***c* so that the partition wall **430***c* tilts toward the pressure chamber **430***a*. In this way, the operation for electing ink from an arbitrary pressure chamber **430***a* also changes the volume in another pressure chamber **430***b* adjacent to the arbitrary pressure chamber **430***a*, which in turn causes the change in pressure in the ink in the adjacent pressure chamber **430***b*. When the ink is ejected from the adjacent pressure chamber **430***b*, there arises a problem of so-called cross talk in some cases in which the velocity and the volume of ejected ink droplets become varied or non-uniform, thereby lowering the printing quality of the ink-jet head **420**.

SUMMARY OF THE INVENTION

The present invention is made to solve the abovementioned problems, an object of which is to provide a piezoelectric actuator, a fluid transporting apparatus and an ink-jet head which are capable of applying a sufficient amount of deformation to the piezoelectric material plate even when the surface area of piezoelectric material arranged between the electrodes is decreased; in which the deformation of the portion of the actuator, corresponding to one of the pressure chambers, is prevented from affecting other portion of the actuator corresponding to another pressure chamber; in which the printing quality can be enhanced and a satisfactory energy efficiency can be realized. Another object of the present invention is to provide a liquid transporting apparatus provided with a piezoelectric actuator which has excellent durability and in which the driving efficiency is further enhanced, and a method for producing such a liquid transporting apparatus.

According to a first aspect of the present invention, there is provided a liquid transporting apparatus including: a plate-shaped body including first and second surfaces which are separated from each other by a predetermined distance in a thickness direction and which extend in a predetermined planar direction substantially perpendicular to the thickness direction, and an operation portion having a first portion and a pair of second portions disposed symmetrically on either side of the first portion with respect to the planar direction; at least one electrode located in each of the second portions, the at least one electrode including at least one pair of electrodes to sandwich an active portion, the active portion being defined in each of the second portions between the pair of electrodes and located nearer to the first surface than the second surface in the thickness direction, at least the active portion in the plate-shaped body being formed from piezoelectric material, the at least one pair of electrodes generating an electric field for deforming the active portion in the planar direction, thereby archingly deforming each of the second portions in a direction from one to the other of the first and second portions, and consequently archingly deforming the first portion in an opposite direction from the other to the one of the first and second portions, thereby deforming the operation portion in the thickness direction; a fluid accommodating plate disposed to face one of the first surface and the second surface of the plate-shaped body, the fluid accommodating plate forming a fluid accommodating chamber, the operation portion of the plate-shaped body confronting the fluid accommodating chamber, volume of the fluid accommodation chamber changing in association with the deformation of the first portion and of the pair of second portions to transport fluid in the fluid accommodation chamber; a hole-defining portion defining an ejection hole in fluid communication with the fluid accommodating chamber, change in volume of the fluid accommodation chamber transporting the fluid in the fluid accommodation chamber through the ejection hole; wherein a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the fluid accommodating chamber, and A is a length in the radial direction of a portion of the at least one electrode, the portion being formed at an area which overlaps with one side portion in the radial direction of the at least one electrode and an edge portion of the fluid accommodating chamber, the edge portion being other than a central portion of the fluid accommodating chamber.

According to a second aspect of the present invention, there is provided a liquid transporting apparatus including: a channel unit having a plurality of pressure chambers each of which is arranged along a plane; and a piezoelectric actuator which selectively changes volumes of the pressure chambers to apply pressure to a liquid in the pressure chambers; wherein the piezoelectric actuator includes: a vibration plate joined to the channel unit to cover the pressure chambers; a piezoelectric layer which is arranged on a side of the vibration plate opposite to the pressure chambers and which is formed to overlap entirely with the pressure chambers as viewed in a direction perpendicular to the plane; a plurality of individual electrodes each of which is formed at an area of the piezoelectric layer, the area being in one surface of the piezoelectric layer and overlapping with an edge portion of one of the pressure chambers as viewed in the direction perpendicular to the plane, the edge portion being other than a central portion of one of the pressure chambers; and a common electrode which is formed on the other surface of the piezoelectric layer; wherein a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the pressure chambers, and A is a length of portions of the individual electrodes in the radial direction, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers.

In the liquid transporting apparatus of the present invention, each of the individual electrodes in the piezoelectric actuator is arranged at the area overlapping with the edge portion of one of the pressure chambers. Accordingly, when a drive voltage is applied to one of the individual electrodes, a portion of the piezoelectric layer, which is sandwiched between the individual electrode and the common electrode and is along the edge portion of one of the pressure chambers is contracted in a direction parallel to the plane of the piezoelectric layer. As a result, the vibration plate and the piezoelectric layer are archingly deformed to project toward a side opposite to one of the pressure chambers, with the portion of the piezoelectric layer overlapping with the central portion of one of the pressure chamber as apex of the archingly deformation, thereby increasing the volume of the pressure chamber and generating a pressure wave inside the pressure chamber. Further, when the application of drive voltage to the individual electrode is stopped at timing when the pressure wave in the pressure chamber changes to positive in the pressure chamber, the vibration plate is restored to the initial or original shape, thereby reducing the volume inside the pressure chamber. However, at this time, the pressure wave generated with the increase in the volume of the pressure chamber and the pressure wave generated with the restoration of the vibration plate are combined and a substantial pressure is applied to the liquid in the pressure chamber. Therefore, it is possible to apply a substantial pressure to the liquid with a comparatively low drive voltage, thereby improving a drive efficiency of the piezoelectric actuator. Moreover, since the electric field is made to act on the piezoelectric layer by applying the drive voltage to the individual electrodes only at a timing of ink transportation, polarization deterioration hardly occurs in the piezoelectric layer, and accordingly the durability of the actuator is improved.

Further, when the value of A/(W/2) is within a range of not less than 0.33 to not more than 0.75 wherein W is the length in the radial direction of the pressure chambers (a length of the pressure chambers in a direction of a straight line passing through the center of surface area of the pressure chambers), and A is the length in the radial direction of portions of the individual electrodes, each of the portions overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers, then it is possible to deform the piezoelectric layer more greatly while suppressing the variation in the amount of deformation of the piezoelectric layer, thereby improving the driving efficiency of the piezoelectric actuator.

In the liquid transporting apparatus of the present invention, the value of A/(W/2) may be not less than 0.41 and not more than 0.69, and the value of A/(W/2) may be not less than 0.41 and not more than 0.55. In this manner, when the length A in the radial direction of the individual electrodes are small within the range of the value of A/(W/2) in the liquid transporting apparatus of the present invention, it is possible to make capacitance generated in the piezoelectric layer between the individual electrodes and the common electrode to be small while increasing the amount of deformation of the piezoelectric layer, thereby making the power consumption of the piezoelectric actuator to be small.

In the liquid transporting apparatus of the present invention, each of the pressure chambers may have a shape long in a predetermined direction; and each of the individual electrodes may be formed at least at two areas which are included the area which overlaps with the edge portion of one of the pressure chambers and which extend substantially in parallel to the predetermined direction. When each of the pressure chambers has a shape which is long in a predetermined direction, a length of the individual electrodes in a direction, which intersects the longitudinal direction (the predetermined direction) of the pressure chamber, greatly affects the amount of deformation of the piezoelectric layer. For this reason, the length A of the individual electrodes, each of which is formed at least in two areas which are included in the area overlapping with the edge portion of one of the pressure chambers and which extend in the longitudinal direction of one of the pressure chambers, the length being in the direction intersecting the longitudinal direction (corresponding to the radial direction in the liquid transporting apparatus of the present invention) of the pressure chamber, is made to have an appropriate value such that the amount of deformation of the piezoelectric layer is great. With this, it is possible to assuredly improve the driving efficiency of the piezoelectric actuator.

In the liquid transporting apparatus of the present invention, the vibration plate may be formed of a metallic material and may serve as the common electrode. In this case, there is no need to separately provide a common electrode in addition to the vibration plate. Further, in the liquid transporting apparatus of the present invention, the vibration plate may be insulative at least on a surface of the vibration plate opposite to the pressure chambers; and the common electrode may be formed on the surface of the vibration plate opposite to the pressure chambers. Alternatively, in the liquid transporting apparatus of the present invention, the vibration plate may be insulative at least on a surface of the vibration plate opposite to the pressure chambers; and the individual electrodes may be formed on the surface of the vibration plate opposite to the pressure chambers.

According to a third aspect of the present invention, there is provided a method for producing a liquid transporting apparatus provided with a channel unit having a plurality of pressure chambers each of which is arranged along a plane; and a piezoelectric actuator including a vibration plate which covers the pressure chambers, a piezoelectric layer arranged on a side of the vibration plate opposite to the pressure chambers, a plurality of individual electrodes each of which is formed at an area of the piezoelectric layer, the area being in one surface of the piezoelectric layer and overlapping with an edge portion of one of the pressure chambers as viewed in a direction perpendicular to the plane, the edge portion being other than a central portion of one of the pressure chambers, and a common electrode which is formed on the other surface of the piezoelectric layer, the method comprising: an electrode length determination step of determining a length A in a radial direction of the individual electrodes based on a relationship between an amount of deformation of the vibration plate when a voltage is applied to the individual electrodes and a value of A/(W/2) in which W is a length in the radial direction of the pressure chambers, and A is a length in the radial direction of portions of the individual electrodes, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers; and an individual electrode formation step of forming the individual electrodes having the length A determined in the electrode length determination step.

In the electrode length determination step, the length A in the radial direction of the individual electrodes is determined to have an optimum value such that the amount of deformation of the vibration plate is great, the length A being determined based on the relationship between the amount of deformation of the vibration plate when a drive voltage is applied to the individual electrodes and the value of A/(W/2), which is a ratio of A to half value of W (W/2) wherein W is a length in the radial direction of the pressure chambers, and A is a length in the radial direction of portions of the individual electrodes, each of the portions being formed at an area overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers; and in the individual electrode formation step, the individual electrodes having the determined length A are formed. Accordingly, it is possible to deform the vibration plate more effectively, thereby improving the efficiency of the piezoelectric actuator.

The method for producing the liquid transporting apparatus of the present invention may include a piezoelectric layer formation step of forming the piezoelectric layer so as to entirely cover the pressure chambers. When the piezoelectric layer is formed so as to entirely cover the pressure chambers, the variation in the rigidities of the vibration plate and piezoelectric layer is small and roughly uniform in the area overlapping with the pressure chambers. Accordingly, even when the conditions such as the thickness of the vibration plate and/or the thickness of the vibration plate are changed, there is no change in the tendency of the vibration plate regarding the amount of deformation with respect to the length A in the radial direction of the individual electrodes. Namely, an optimal value for the length A in the radial direction of the individual electrodes, such that the amount of deformation of the vibration plate when voltage is applied to the individual electrodes is great, does not depend on the conditions other than the length W in the radial direction of the pressure chambers, i.e. the conditions such as the thickness of the vibration plate and/or the thickness of the piezoelectric layer. Therefore, it is easy to determine the optimal value for the length A in the radial direction of the individual electrodes.

The method for producing the liquid transporting apparatus of the present invention may include: a vibration plate thickness measurement step of measuring a thickness of the vibration plate; a piezoelectric layer formation step of forming the piezoelectric layer at areas on a surface of the vibration plate opposite to the pressure chambers, each of the areas overlapping with the edge portion of one of the pressure chambers, such that a plurality of openings are formed at locations overlapping with central portions of the pressure chambers respectively as viewed in the direction perpendicular to the plane; a piezoelectric layer thickness measurement step of measuring a thickness of the piezoelectric layer; and an opening length measurement step of measuring a length in the radial direction of the openings, each of the openings overlapping with one of the pressure chambers and being an area in which the piezoelectric layer is partially absent as viewed in the direction perpendicular to the plane; wherein in the electrode length determination step, the relationship between the amount of deformation of the vibration plate when the voltage is applied to the individual electrodes and the value of A/(W/2) may be determined based on the thickness of the vibration plate, the thickness of the piezoelectric layer, and the length in the radial direction of the openings; and the length A in the radial direction of the individual electrodes may be determined based on the determined relationship.

When the piezoelectric layer is not formed at a portion which overlaps with the central portion of the pressure chamber and at which the individual electrode is not arranged, the rigidity of the piezoelectric actuator differs at the area overlapping with the central portion of the pressure chamber and another area overlapping with the edge portion of the pressure chamber. Accordingly, the relationship between the value of A/(W/2) and the amount of deformation of the vibration plate when the voltage is applied to the individual electrodes depends on each of the thickness of the vibration plate, the thickness of the piezoelectric layer, and the length in the radial direction of the openings. Accordingly, in the present invention, the thickness of the vibration plate, the thickness of the piezoelectric layer, and the length of the openings are measured, and based on the results of measurement, the relationship between the value of A/(W/2) and the amount of deformation of the vibration plate when voltage is applied to the individual electrodes is determined. Accordingly, it is possible to appropriately determine the value of A such that the amount of deformation of the vibration plate becomes great.

In the liquid transporting apparatus of the present invention, the pair of electrodes in each of the second portions may be disposed in confrontation with each other to sandwich the active portion therebetween in a predetermined direction, the predetermined direction being either one of the planar direction and the thickness direction, the active portion being polarized in a direction parallel to the predetermined direction, the electric field generated between the confronting electrodes in the predetermined direction changing a length of the active portion in the planar direction, thereby bending the corresponding second portions in the direction from one to the other of the first surface and the second surface, and consequently bending the first portion in the opposite direction from the other to the one of the first surface and the second surface, thereby deforming the operation portion in the thickness direction; the plate-shaped body may include a piezoelectric layer which is formed of a piezoelectric material and which defines the first surface, and the pair of electrodes which is formed to sandwich the piezoelectric layer therebetween to define the active portion in the piezoelectric layer sandwiched between the electrodes; the pair of electrodes in each of the second portions may include a first surface electrode and a second surface electrode, the first surface electrode being disposed on the first surface, the second surface electrode of the pair of electrodes in each of the pair of second portions being integrated with a metal layer formed of metal, and the metal layer defining the second surface on a surface of the metal layer opposite to the other surface thereof facing the piezoelectric layer; the active portion may be defined in each of the second portions at a location between the first surface electrode and the second surface electrode, the first surface electrode and the second surface electrode generating the electric field for deforming the active portion in the planar direction.

In the liquid transporting apparatus of the present invention, the pair of electrodes in each of the second portions may be disposed in confrontation with each other to sandwich the active portion therebetween in a predetermined direction, the predetermined direction being either one of the planar direction and the thickness direction, the active portion being polarized in a direction parallel to the predetermined direction, the electric field generated between the confronting electrodes in the predetermined direction changing a length of the active portion in the planar direction, thereby bending the corresponding second portions in the direction from one to the other of the first surface and the second surface, and consequently bending the first portion in the opposite direction from the other to the one of the first surface and the second surface, thereby deforming the operation portion in the thickness direction; the plate-shaped body may include a plurality of operation portions made of a plurality of piezoelectric material portions, the piezoelectric material portions being arranged in the planar direction separately from one another in the planar direction, the piezoelectric material portions defining the first surface; the pair of electrodes in each of the second portions may include a first surface electrode and a second surface electrode, the first surface electrode being disposed on the first surface, the second surface electrode of the pair of electrode in each of the pair of second portions being integrated with a metal layer formed of metal, and the metal layer defining the second surface on a surface of the metal layer opposite to the other surface thereof facing the piezoelectric material portions; and the active portion may be defined in each of the second portions at a location between the first surface electrode and the second surface electrode, the first surface electrode and the second surface electrode generating the electric field for deforming the active portion in the planar direction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of major portions of an ink-jet printer **101**.

FIG. **2** is an exploded perspective view of an ink-jet head **100**.

FIG. **3** is an exploded perspective view of a cavity plate **10**.

FIG. **4** is an exploded sectional perspective view of major portions of the cavity plate **10** as viewed in a direction of an arrow taken along a one-dot chained line A-A' in FIG. **2**.

FIG. **5** is an exploded sectional perspective view of major portions of a piezoelectric actuator **50** as viewed in a direction of an arrow taken along a one-dot chained line B-B' (V-V) in FIG. **2**.

FIG. **6** is a partial sectional view of major portions of the ink-jet head **100** as viewed in a direction of an arrow taken along a one-dot chained line C-C' in FIG. **2**.

FIG. **7** is a partial sectional view of major portions of the ink-jet head **100** as viewed in a direction of an arrow taken along a one-dot chained line D-D' in FIG. **2**.

FIG. **8** is a partial enlarged sectional view of the piezoelectric actuator **50**.

FIG. **9** is a sectional view of the piezoelectric actuator **50** corresponding to FIG. **6** when voltage is applied to the actuator.

FIG. **10** is a sectional view of the piezoelectric actuator **50** corresponding to FIG. **6** when the application of the voltage to the actuator is stopped.

FIG. **11** is a partial sectional view of an ink-jet head **100** of a second embodiment.

FIG. **12** is a partial sectional view of an ink-jet head **100** of a third embodiment.

FIG. **13** is a partial sectional view of an ink-jet head **100** of a fourth embodiment.

FIG. **14** is a partial sectional view of an ink-jet head **100** of a fifth embodiment.

FIG. **15** is a sectional view of an ink-jet head **301** of a sixth embodiment, substantially parallel to the longitudinal direction of a pressure chamber **310**.

FIG. **16** is a sectional view of the ink-jet head **301** of the sixth embodiment, along a direction in which the pressure chambers **310** are arranged.

FIG. **17** is an enlarged view of a portion of a piezoelectric actuator plate **305** and the pressure chamber **310** shown in FIG. **16**.

FIG. **18** is a sectional view showing a state when the piezoelectric actuator plate **305** of FIG. **16** is deformed.

FIG. **19** is a reference drawing for explaining the operation in FIG. **18**.

FIG. **20** is a sectional view of an ink-jet head of a seventh embodiment.

FIG. **21** is a sectional view showing a state when the piezoelectric actuator plate **305** in FIG. **20** is deformed.

FIG. **22** is a sectional view of an ink-jet head of an eighth embodiment.

FIG. **23** is a partial sectional view of an ink-jet head **100** of a ninth embodiment.

FIG. **24** is a schematic perspective view of an ink-jet head according to a tenth embodiment of the present invention.

FIG. **25** is a plan view of an ink-jet head.

FIG. **26** is a partial enlarged view of FIG. **25**.

FIG. **27** is a sectional view of FIG. **26** taken along a line XXVII-XXVII.

FIG. **28** is a sectional view of FIG. **26** taken along a line XXVIII-XXVIII.

FIG. **29** is a drawing showing a state in which the piezoelectric layer and the vibration plate are deformed when driving voltage is applied to an individual electrode.

FIG. **30** is a graph showing a relationship between a value of A/(W/2) and a maximum amount of displacement of the vibration plate.

FIG. **31** is a graph showing a relationship between the maximum amount of displacement of the vibration plate and a velocity of ink droplet.

FIG. **32** (FIGS. **32**A to **32**D) shows a process for producing an ink-jet head, wherein FIG. **32**A shows a joining step of metallic plates, FIG. **32**B shows a piezoelectric layer formation step, FIG. **32**C shows an individual electrode formation step, and FIG. **32**D shows a joining step of a nozzle plate.

FIG. **33** is a sectional view of a first modified embodiment corresponding to FIG. **28**.

FIG. **34** is a sectional view of a second modified embodiment corresponding to FIG. **28**.

FIG. **35** is a sectional view of a third modified embodiment corresponding to FIG. **28**.

FIG. **36** is a partial enlarged plan view of an ink-jet head of a fourth modified embodiment.

FIG. **37** is a partial enlarged plan view of an ink-jet head of a fifth modified embodiment.

FIG. **38** is a sectional view of an ink-jet head of an eleventh embodiment corresponding to FIG. **27**.

FIG. **39** is a sectional view of the ink-jet head of the eleventh embodiment corresponding to FIG. **28**.

FIG. **40** is a graph showing a relationship between the value of A/(W/2) and the maximum amount of displacement of the vibration plate.

FIG. **41** is a graph showing a tendency of change in the maximum amount of displacement of the vibration plate when a thickness Tv of the vibration plate is changed.

FIG. **42** is a graph the tendency of change in the maximum amount of displacement of the vibration plate when a thickness Tp of the piezoelectric layer is changed.

FIG. **43** is a graph showing the tendency of change in the maximum amount of displacement of the vibration plate when a width S of the opening is changed.

FIG. **44** (FIGS. **44**A to **44**D) shows a process for producing the ink-jet head of the eleventh embodiment, wherein FIG. **44**A shows a joining step of metallic plates,

FIG. **44**B shows a piezoelectric layer formation step, FIG. **44**C shows an individual electrode formation step, and FIG. **44**D shows a joining step of a nozzle plate.

FIG. **45**A is a partial sectional view of an ink-jet head **700** of a twelfth embodiment provided with a piezoelectric actuator **750** which has a metal layer **751**;

FIG. **45**B is a partial sectional view of the ink-jet head **700** of the twelfth embodiment provided with the piezoelectric actuator **750** which has an insulation layer **754**.

FIG. **46**A shows a partial sectional view of an ink-jet head **700** of a thirteenth embodiment provided with a piezoelectric actuator **750** which has a metal layer **751**; FIG. **46**B shows the ink-jet head **700** of the thirteenth embodiment provided with the piezoelectric actuator **750** which has an insulation layer **754**.

FIG. **47** is a sectional view of a conventional ink-jet head **420**.

FIG. **48** is a sectional view showing a state in which the piezoelectric actuator plate **421** of FIG. **47** is deformed.

PREFERRED EMBODIMENT OF THE INVENTION

First Embodiment

In the following, a first embodiment of the present invention will be explained with reference to the drawings. First, with reference to FIG. **1**, an explanation will be given about a construction of an ink-jet printer **101** carrying an ink-jet head **100** as an example of a fluid transporting apparatus provided with a piezoelectric actuator. FIG. **1** is a perspective view of major portions of the ink-jet printer **101**.

As shown in FIG. **1**, the ink-jet printer **101** includes a platen roller **110** as a sheet transporting means to transport a sheet **111** as a recording objective, and a carriage **118** on which an ink-jet head **100** and an ink cartridge **116** to be filled with an ink are to be mounted. The ink-jet head **100** is arranged in the carriage **118** at a position facing the platen roller **110** to perform printing on the sheet **111**. The platen roller **110** is rotatably attached to a frame **113** by a shaft **112**, and is driven to rotate by a motor **114**. The carriage **118** is slidably supported by two guide rods **120**, which are arranged in parallel with the rotational axis of the platen roller **110**, and is coupled to a timing belt **124** provided around a pair of pulleys **122**. One of the pulleys **122** is driven in both forward and in reverse directions by a motor **123**, thereby reciprocating the carriage **118** along the platen roller **110**.

The sheet **111** is supplied from a sheet supply cassette (not shown) provided to the side of the ink-jet printer **101**, and transported between the ink-jet head **100** and the platen roller **110**. The ink-jet head **100** ejects ink onto the sheet **111** to perform a predetermined printing on the sheet **111**. Afterward, the sheet **111** is discharged from the ink jet printer **101**. It should be noted that mechanisms for supplying and discharging the sheet **111** are omitted in FIG. **1**.

Next, with reference to FIGS. **2** to **7**, an explanation will be given about a construction of the ink-jet head **100** provided with a piezoelectric actuator **50** of the first embodiment. FIG. **2** is an exploded perspective view of the ink-jet head **100**. FIG. **3** is an exploded perspective view of a cavity plate **10**. FIG. **4** is an exploded sectional perspective view of major portions of the cavity plate **10** as viewed in a direction of an arrow taken along a one-dot chained line A-A' in FIG. **2**. FIG. **5** is an exploded sectional perspective view of major portions of the piezoelectric actuator **50** as viewed in a direction of an arrow taken along a one-dot chained line B-B' in FIG. **2**. FIG. **6** is a partial sectional view of the cavity plate **10** and the piezoelectric actuator **50** as viewed in a direction of an arrow taken along a one-dot chained line C-C' in FIG. **2**. FIG. **7** is a partial sectional view of the cavity plate **10** and the piezoelectric actuator **50** as viewed in a direction of an arrow taken along a one-dot chained line D-D' in FIG. **2**.

As shown in FIG. **2**, the ink-jet head **100** is constructed of a cavity plate **10**, a piezoelectric actuator **50**, and a flexible flat cable **40** stacked on and joined to each other with an adhesive. The piezoelectric actuator **50** has a plate shape and is stacked on and adhered to the cavity plate **10** via adhesive or an adhesive sheet. The cavity plate **10** is constructed of a plurality of sheets stacked in a laminated state. The flexible flat cable **40** is stacked on and adhered to the upper surface of the piezoelectric actuator **50** so as to electrically connect the piezoelectric actuator **50** to an external device. The cavity plate **10**, which is the lowermost layer of the stack, is provided with nozzles **15** (see FIG. **3**) which are open on a lower surface of the cavity plate **10** and through which the ink is ejected downwardly.

As shown in FIG. **3**, the cavity plate **10** is constructed of five thin metal plates, namely a nozzle plate **11**, two manifold plates **12**, a space plate **13** and a base plate **14** in which these five plates are stacked on each other in a laminated state and joined together with an adhesive. Each of these plates **11** to **14** is made of, for example, a 42% Nickel alloy steel plate (42 alloy) and has a thickness of about 50 μm to 150 μm.

As shown in FIGS. **4**, **6**, and **7**, a plurality of narrow-width pressure chambers **16** are formed through the base plate **14**. The pressure chambers **16** are juxtaposed in staggered rows on the base plate **14**. The pressure chambers **16** extend in a direction perpendicular to center lines **14***a*, **14***b* which indicate the longitudinal direction of the base plate **14**. The pressure chambers **16** are separated from one another by partition walls **14***c*. Ink supply holes **16***b* are formed also on the base plate **14** corresponding to the pressure chambers **16** respectively. Each of the ink supply holes **16** is formed through the base plate at a position on a right or left edge side of one of the pressure chambers in a short direction of the base plate **14**. Throttle sections **16***d* are formed between the pressure chambers **16** and the ink supply holes **16***b* so as to connect the pressure chambers **16** and the ink supply holes **16***b* respectively. Ink supply holes **18** are formed through the space plate **13** at positions on left and right portions respectively in a short direction of the manifold plate **13**. Each of the ink supply holes **16***b* communicates, through one of the ink supply holes **18**, with one of common ink chambers **12***a* in the manifold plate **12**. Each of the throttle sections **16***d* is formed with a smaller cross-sectional area than that of the pressure chamber **16**, with respect to a direction perpendicular to a direction of the ink flowing through the throttle section **16***d*. The throttle sections **16***d* are formed to have the smaller cross-sectional area so as to increase the resistance in the channel. Further, small-diameter through-holes **17** are formed through the spacer plate **13** and the two manifold plates **12** in the same staggered pattern as the pressure chambers **16**. Each of the pressure chambers **16** has an end portion **16***a*. Each of the small-diameter through-holes **17** is communicated with the end portion **16***a* of one of the pressure chambers **16**. It should be noted that the pressure chamber **16** is the "fluid accommodating chamber" in the present invention, and the base plate **14** is the "fluid accommodating plate" in the present invention.

As shown in FIGS. **3**, **6** and **7**, the spacer plate **13** is formed with ink supply holes **19***b*, and the base plate **14** is formed with ink supply holes **19***a*. The ink supply holes **19***a*, **19***b* are for supplying ink from the ink cartridge **116** to common ink chambers **12***a* of the manifold plates **12**. In the two manifold plates **12**, two ink chambers **12***a* are provided along the longitudinal direction of the plate, with the arrays formed by the plurality of nozzles **15** in the nozzle plate **11** intervening between the ink common chambers. These common ink chambers **12***a* are formed through each of the manifold plates **12**, and located within a plane parallel to a plane defined by the plurality of pressure chambers **16** in the base plate **14**. Further, the common ink chambers **12***a* are formed in the two manifold plates **12** such that the common ink chambers **12***a* are positioned closer to the nozzle plate **11** than the pressure chambers **16**, and that the common ink chambers extend longer than the pressure chambers **16** in a direction of the arrays defined by the plurality of nozzles **15**.

Each of the ink common chambers **12***a* includes an end portion (C portion) disposed at a position apart from the ink supply holes **19***a*, **19***b*, and has a shape such that the cross-sectional area at the C portion is decreased at a fixed rate in a direction farther away from the ink supply holes **19***a*, **19***b*. This shape facilitates the discharge of residual air bubbles which tend to be trapped or collected in the end portion (C portion) in the common ink chambers **12***a*. The common ink chambers **12***a* are constructed such that the common ink chambers are sealed by the nozzle plate **11** and the spacer plate **13** stacked on either side of the two manifold plates **12**.

The nozzles **15** are formed through the nozzle plate **11** aligned in staggered rows along center lines **11***a*, **11***b* which extend in the longitudinal direction of the nozzle plate **11**. Each of the nozzles **15** has a small diameter of, for example, about 25 μm. The nozzles **15** in one of the rows are staggered from the nozzles **15** of the other row, and adjacent nozzles **15** of the same row are separated by a small pitch P. Each of the nozzles **15** corresponds to one of the through-holes **17** of the manifold plates **12**. The nozzle **15** is the "ejection hole" and the nozzle plate **11** is the "hole-defining portion" in the present invention.

As shown in FIGS. **5** to **7**, the piezoelectric actuator **50** is constructed of a stack of six piezoelectric sheets **51**, **52**, **53**, **54**, **55**, **56** formed from a lead zirconate titanate (PZT) type piezoelectric ceramic material. On the upper surface of each of these piezoelectric sheets **54** to **56**, electrodes, to be described later on, will be formed, for example, by screen printing using a conductive paste material or by deposition of a conductive material. The collective body, formed of the piezoelectric sheets **51** to **56**, is the "plate-shaped body" in the present invention.

On the upper surfaces of the piezoelectric sheets **54** and **56**, a plurality of drive electrodes **24** are provided in a staggered array in a one-to-one correspondence to the pressure chambers **16** in the cavity plate **10**, extending in a direction perpendicular to the longitudinal direction of the piezoelectric sheet **54** or **56**. Each of the drive electrodes **24** is formed so as to cover the surface area of the corresponding pressure chamber **16** in the planar direction of the cavity plate **10**, and formed to have a circular shape to be arranged along an outer periphery of the corresponding pressure chamber **16**. Each of the drive electrodes **24** includes a wiring portion **24***a* which is formed to extend from one end of each drive electrode **24**. The wiring portions **24***a* are exposed in left or right side surfaces **50***c* in the longitudinal direction of the piezoelectric actuator **50**, the side surfaces **50***c* being disposed on left or right sides perpendicular to top and bottom sides **50***a*, **50***b* of the piezoelectric actuator **50**.

On the upper surfaces of the piezoelectric sheets **53** and **55**, a plurality of common electrodes **25** are formed as a ground electrode which is common for the pressure chambers **16**. The common electrodes **25** are arranged at positions corresponding to the drive electrodes **24** respectively, in a staggered array similar to the drive electrodes **24**. The common electrodes **25** have the same shape as the drive electrodes **24**, and include wiring portions **25***a* each of which extends from one end thereof. Each of the wiring portions **25***a* is connected to a common wiring portion **25***b* which extends along the center of the piezoelectric sheets **53** or **55** in the longitudinal direction of the piezoelectric sheets **53** or **55**. The ends of the common wiring portion **25***b* are connected to common wiring portions **25***c* arranged to extend along both end portions in the longitudinal direction of the piezoelectric sheets **53** or **55**. Both ends of the common wiring portion **25***c* are exposed in the left and right side surfaces **50***c* respectively, in the same manner as the wiring portions **24***a* of the drive electrodes **24**.

It should be noted that electrodes **28**, **29** serve as dummy patterns and are formed along both ends in the longitudinal direction of the piezoelectric sheets **53** to **56** at positions which correspond to the wiring portions **25***c*, **24***a*, respectively.

In the left and right side surfaces **50***c* of the piezoelectric actuator **50**, first grooves **30** and second grooves **31** are formed so as to extend in the direction in which the piezoelectric sheets **51** to **56** are stacked. The first grooves **30** are formed to correspond to the wiring portions **24***a* of the drive electrodes **24** respectively. The second grooves **31** are formed to correspond to the both end portions of each of the common wiring portions **25***c* of the common electrodes **25**. Although not shown in the drawings, side-surface electrodes are formed in the first and second grooves **30**, **31**. The side-surface electrodes in the first grooves **30** electrically connect the drive electrodes **24** and the dummy pattern electrodes **29** respectively, and the side surface electrodes in the second grooves **31** electrically connect the common electrodes **25** and the dummy pattern electrodes **28** respectively. As shown in FIG. **2**, an insulating sheet **23** is adhered to the upper surface of the piezoelectric actuator **50** (on the side of the stacked piezoelectric sheet **56**). Electrodes **26**, **27** are provided on the insulation sheet **23**, and the side surface electrodes **30**, **31** are connected to electrodes **26**, **27**, respectively. That is, the drive electrodes **24** are electrically connected to the electrodes **26** respectively, and the common electrodes **25** are electrically connected to the electrodes **27** respectively. Each of the electrodes **26**, **27** is connected to a corresponding contact point (not shown) of the flexible flat cable **40**. It should be noted that the electrodes can be connected to the flexible flat cable **40** alternatively with electric through-holes penetrating through the piezoelectric sheets in the stacking direction, other than the above-described method for extending the electrodes.

The piezoelectric sheets **54**, **56**, which are formed with the drive electrodes **24**, are stacked in alternation with the piezoelectric sheet **53**, **55**, which are formed with the common electrodes **25**. Then, the sheets **51**, **52**, which are not formed with any electrodes, are stacked on the pressure chamber **16** side of the piezoelectric sheet **53**. The stack of piezoelectric sheets **51** to **56** are then sintered into an integral block. In a well-known manner, the portions in the piezoelectric sheets **54** to **56**, interposed between the electrodes **24**, **25** in the stacked direction, are polarized by connecting the common electrodes **25** to ground (GND) and applying the drive electrodes **24** with a high, positive voltage for polarization through the electrodes **26**, **27**, the portions being polarized in a direction P from the drive electrodes **24** to the common electrodes **25** (see FIG. **8**).

The electrodes **24**, **25** of the piezoelectric actuator **50** are positioned in a circular manner along the outer periphery of the pressure chambers **16** in a plan view, as shown in FIGS. **6** and **7**. In this piezoelectric actuator **50**, the portion having the electrodes **24**, **25** in a plan view is designated as "second portion" S, and the portion surrounded by the second portion S in a plan view is designated as "first portion" F, respectively. Namely, in the direction of cross section, a pair of second portions S (although the second portion is actually continuously formed in a circular manner) is disposed on both sides of a first portion F respectively. The electrodes **24**, **25** are unevenly disposed in a thickness direction of each of the second portions S, at a location away from the corresponding pressure chamber **16**. In the stack direction of the piezoelectric sheets **54** to **56**, the portions which are sandwiched between the electrodes **24**, **25** construct a pressure generating portion which deforms due to the piezoelectric effect when applied with a voltage, and first and second portion F, S construct an operation portion which deforms based on the deformation of the pressure generating portion.

The piezoelectric actuator **50** is joined to the cavity plate **10** such that the operation portions, each of which is formed of one first portion F and second portion S disposed on both sides of the first portion, correspond to the pressure chambers **16**, respectively. At this time, the lower surface portions of the outer sides of the second portions S with respect to the first portions F (namely, portions in between adjacent operation portions) are positioned above partition walls **14***c* between the pressure chambers **16** and firmly attached to the partition walls **14***c*, respectively. In the present invention, the partition wall **14***c* constructs "fixed portion" in the present invention.

As shown in FIG. **6**, in an initial condition, the drive electrodes **24** and the common electrodes **25** are all connected to ground (GND) and thus have an electric potential of 0V. Also, ink supplied from the common ink chambers **12***a* fills the pressure chambers **16** up to the end portions of the nozzles **15**.

When, according to a predetermined print data, ink is to be ejected from a nozzle **15** communicating with one of the pressure chambers **16**, then as shown in FIG. **9**, drive voltage is applied to a pressure-generating portion corresponding to the pressure chamber **16**. That is, the drive voltage of, for example, 20V is applied to the electrodes **24** while the common electrodes **25** are maintained in connection with ground (GND). At this time, as shown in FIG. **8**, since the direction P of polarization matches the direction E of the electric field, the piezoelectric vertical effect elongates the portions of the piezoelectric sheets **54** to **56**, located between the electrodes **24** and **25**, in the direction P of polarization. It is noted, however, that each of the portions of the piezoelectric sheet **54** to **56** between the electrodes **24** and **25** is sufficiently wider in the planar direction H, which is perpendicular to the direction P of polarization, than it is thick in the direction P of polarization. Therefore, the piezoelectric horizontal effect greatly contracts the portions of the piezoelectric sheet **54** to **56** in the planar direction H.

While the pressure generating portion contracts in the planar direction H, however, portions of piezoelectric sheets **51** to **53**, which are sandwiched between no electrodes and which are located adjacent to the pressure generating portion in the stack direction, do not deform. Therefore, as shown in FIG. **9**, the second portion S overall bends in an arch shape with the pressure-generating portion being positioned at the valley of the arch. At this time, since the second portion S is fixed to a partition wall **14***c* at the outer side thereof, the second portion S arches or bends, at the side nearer to the first portion F, greatly in a direction away from the cavity plate **10**. Further, with respect to a pressure chamber **16**, a pair of second portions S disposed along the outer periphery of the pressure chamber **16** bends symmetrically with respect to the center of the pressure chamber. Therefore, the bending action of the second portions S presses the corresponding first portion F to project upward in the direction substantially perpendicular to the planar direction of the piezoelectric actuator. Namely, both the first and second portions F, S bend in a direction that increases the volume of the pressure chamber **16**. As a result, the pressure in the pressure chamber **16** reduces to a negative pressure so that ink is supplied to the pressure chamber **16** from the common ink chamber **12***a*.

At this time, pressure waves are generated in the pressure chamber **16**. As is well known, when the time required for the pressure waves to propagate one-way in the longitudinal direction of the pressure chamber **16** is elapsed, the pressure in the pressure chamber **16** switches to a positive pressure. Therefore, the voltage applied to the drive electrodes **24** is released to be switched to 0V at this timing. Then, as shown in FIG. **10**, the pressure-generating portion of the piezoelectric actuator **50** returns to its initial condition before the deformation, and the first and second portions F, S also resiliently revert to the initial flat state.

At this time, the pressure from the positive pressure wave and the pressure generated when the piezoelectric actuator **50** reverts to its initial condition are synthesized to generate a relatively high pressure near a nozzle **15** corresponding to the pressure chamber **16**, and an ink droplet **150** is ejected through the nozzle **15** as a result. In this way, the ink-jet head **100** of the present embodiment is capable of ejecting droplets by a so-called "pulling ejection". It should be noted that, among the six piezoelectric sheets **51** to **56** constructing the piezoelectric actuator **50** of the first embodiment, the three piezoelectric sheets **54**, **55**, **56** disposed on the side of the cavity plate **10** in this order need not to be formed of a piezoelectric material, and may be formed of, for example, a metallic material.

Second Embodiment

Next, an ink-jet head **100** including a piezoelectric actuator **50** according to a second embodiment will be explained with reference to FIG. **11**. It should be noted that the ink-jet head **100** of this embodiment includes a cavity plate **10** with the same configuration as the cavity plate **10** of the first embodiment.

In the same manner as in the first embodiment, the piezoelectric actuator **50** has a first portion F and a pair of second portions S corresponding to each of the pressure chambers **16**. In this embodiment, in the second portions S, electrodes **24**, **25** are arranged between adjacent layers of the piezoelectric sheets **51** to **53** which are located close to the pressure chambers **16** in the thickness direction of the piezoelectric actuator. The common electrodes **25** are arranged between the adjacent layers of the piezoelectric sheets **51** to **53** in the direction in which the piezoelectric sheets are stacked, along the outer periphery of each of the pressure chambers **16**. The drive electrodes **24** are arranged between the adjacent layers of the piezoelectric sheets in the direction in which the piezoelectric sheets are stacked, at locations in which the drive electrodes **24** are spaced, from the corresponding electrodes **25** respectively, to the inner side in the planar direction. The piezoelectric sheets are polarized in the planar direction P of the piezoelectric sheets by applying a high, positive voltage to the drive electrodes **24** and by connecting the common electrodes **25** to ground (GND).

Thus, in the same way as in the above-described embodiment, in the piezoelectric actuator **50** in which the drive electrodes **24** and the common electrodes **25** are arranged in this manner, the drive electrodes **24** and the common electrodes **25** are initially connected to ground (GND) when a printing operation of the ink-jet printer **101** is to be started. Then, when ink is to be ejected, according to a predetermined print data, from a nozzle **15** corresponding to one of the pressure chambers **16**, then, while maintaining the common electrodes **25** in connection with ground (GND), a drive voltage is applied to the drive electrodes **24** that correspond to the pressure chamber **16** that is in fluid communication with the nozzle **15**. As a result, an electric field E, which is in the same direction as the polarization direction P, is generated from the inner-side drive electrodes **24** toward the outer-side common electrodes **25**, thereby increasing, due to the piezoelectric vertical effect, the distance between the drive electrodes **24** and the common electrodes **25** respectively arranged in the planar direction of the piezoelectric actuator **50**.

At this time, the piezoelectric sheets **54** to **56** in which no electrodes are arranged do not deform, and a unimorphic deformation is generated between the piezoelectric sheets **51** to **53** which attempt to elongate in the planar direction. That is, the second portion S archingly deforms, with its side of the piezoelectric sheets **54** to **56** as the inner side of the arch. However, as in the above-described embodiment, since the outer periphery of the pressure chamber **16** is fixed, the second portion S deforms greatly upward at its portion that is substantially nearer to the center of the pressure chamber **16**. In association with this, the first portion F also archingly bends to protrude upward in a direction away from the pressure chamber **16**. When application of voltage to the drive electrodes **24** is stopped, then the piezoelectric actuator **50** resiliently reverts to its flat condition, thereby applying pressure to the ink in the pressure chamber **16** to eject the ink from the nozzle **15**.

Third Embodiment

Next, an ink-jet head **100** including a piezoelectric actuator **50** according to a third embodiment of the present invention will be explained with reference to FIG. **12**. The piezoelectric actuator **50** of the present embodiment has a configuration similar to the piezoelectric actuator **50** of the first embodiment, except that a notch **57** is formed in the surface of each of the first portions F at a position shifted in the thickness direction of the piezoelectric actuator **50** in the direction in which the first portion F archingly deforms. In other words, the notch **57** is formed on the surface of each of the first portion F opposite to one of the pressure chambers **16**. Further, a connection electrode **58** is formed, for example, by continuously depositing a conductive material on the inner surface of the notch **57** and on the surface of the piezoelectric actuator **50**. A wiring which extends from either the drive electrodes **24** or the common electrodes **25** is connected to the connection electrode **58**, and to an external power source through the connection electrode **58**.

The notch **57** reduces thickness of the first portion F so that thickness of the first portion F is constructed of only a portion located nearer to the pressure chamber **16**, thereby reducing the rigidity of the first portion F. Accordingly, the first portion F bends under deformation of the second portions S with smaller resistance. Thus, as the second portions deforms more greatly, the first portion F also deforms greatly and the volume of the pressure chamber **16** changes also greatly. Here, instead of providing the notch **57**, other configurations can be provided so as to cause the piezoelectric actuator **50** deform easily. For example, the first portion F may be partially formed of a material that has low rigidity. Alternatively, a hollow portion may be formed in a part of the first portion F.

Fourth Embodiment

Next, an ink-jet head **100** including a piezoelectric actuator **50** according to a fourth embodiment of the present invention will be explained with reference to FIG. **13**. The piezoelectric actuator **50** of the present embodiment has a configuration similar to that of the piezoelectric actuator **50** of the first embodiment, except that a small-diameter through-hole **50***d* is opened through the piezoelectric sheets **51** to **56** at each of the first portions F. The nozzle plate **11** is adhered to the front surface **50***a* of the piezoelectric actuator **50**, the surface **50***a* being opposite from the side of the piezoelectric actuator **50** where the pressure chambers **16** are located. Nozzles **15** are opened through the nozzle plate **11** at positions corresponding to the through-holes **50***d* connected to the pressure chambers **16** respectively, in order to bring the nozzles **15** into fluid communication with corresponding pressure chambers **16**.

In this embodiment, when voltage is applied to the piezoelectric actuator **50**, the actuator **50** operates to deform itself in the same manner as the piezoelectric actuator **50** of the first embodiment. The opening portion of the nozzle **15** in the nozzle plate **11**, which is joined to the piezoelectric actuator **50**, also deforms in association with the deformation of the piezoelectric actuator **50**, thereby increasing volume of the pressure chamber **16**. When the piezoelectric actuator **50** reverts to its initial shape, then pressure is applied to the ink in the pressure chamber **16** and ink is ejected through the through-hole **50***d* and from the nozzle **15**.

Fifth Embodiment

FIG. **14** shows a fifth embodiment which has a basically similar configuration as that of the first embodiment, except that the widths of the electrodes **24**, **25** are changed. In other words, as the electrodes **24**, **25** are disposed upper in the drawing, namely nearer to the inner side of the arching deformation (bending), the widths **W1** in the planar direction of the electrodes **24**, **25** becomes larger, and as the electrodes **24**, **25** are disposed lower in the drawing, namely nearer to the outer side of the arching deformation, the widths **W2** in the planar direction of the electrodes **24**, **25** becomes smaller. The electrodes **24**, **25** are arranged such that their outer edges with respect to the corresponding pressure chamber **16** are aligned with each other in the thickness direction (the stacking direction) and such that their inner edges with respect to the corresponding pressure chamber **16** have a stepped configuration toward the inside of the corresponding pressure chamber **16**.

It is necessary that as a pressure-generating portion is disposed nearer to the inner side of the arching deformation, the pressure-generating portion needs to have a larger amount of contraction force in the planar direction than another pressure-generating portion disposed nearer to the outer side of the arching deformation. However, the pressure-generating portion disposed nearer to the outside of the bending formation may have a small amount of contraction force. Therefore, with such an arrangement as described above, the total surface area of the electrodes **24**, **25** can be decreased while maintaining the amount of arching deformation, thereby greatly decreasing the amounts of capacitance and reducing the current.

Sixth Embodiment

Next, a sixth embodiment of the present invention will be explained with reference to FIGS. **15** to **19**. FIG. **15** is a sectional view of an ink-jet head **301** substantially parallel to the longitudinal direction of a pressure chamber. FIG. **16** is a sectional view of the ink-jet head **301** along a direction in which the pressure chambers are arranged. FIG. **17** is an enlarged view of a portion of a piezoelectric actuator plate **305** and the pressure chamber **310** shown in FIG. **16**. As shown in FIGS. **15** and **16**, the ink-jet head **301** is constructed of a piezoelectric actuator **306** and a cavity plate **307**, as similar to the embodiment explained with reference to FIG. **6**.

The cavity plate **307** has a construction basically similar to that of the cavity plate **10** explained with reference to FIG. **6**. In the cavity plate **307**, however, a first layer (uppermost layer) **307***a* and a second layer **307***b* correspond to the base plate **14** and the spacer plate **15**, respectively, and a third plate **307***c* corresponds to the two manifold plates **12**, **12**. A plurality of pressure chambers **310** are formed in the first layer **307***a* and separated from each other by partition walls **310***c*. A manifold channel, namely a common ink channel **315**, is formed in the third layer **307***c*. Each of the pressure chambers **310** is connected to the common ink chamber **315** via an ink supply hole **312** provided in the second layer **307***b*, and is connected to a nozzle **309** in a nozzle plate **308**, which is the lowermost layer, via through holes **311**, **313** provided in the second layer **307***b* and the third layer **307***c*, respectively. These pressure chambers and holes function similarly to those in the cavity plate **10**.

The piezoelectric actuator **306** has a structure basically similar to that of the piezoelectric actuator **50** explained with reference to FIG. **6**, namely the structure having electrodes **326** to **330** which will be described later and each of which is sandwiched between a plurality of piezoelectric sheets **306***a* to **306***f* in a laminated form.

In this embodiment, electrodes **327**, **328**, **326** are provided to be sandwiched between first to fourth layers **306***a* to **306***d* at a portion **305***b* (hereinafter referred to as "second portion") corresponding to a periphery portion of each of the pressure chambers **310** (in FIG. **15**, the second portion is a circular portion formed of both edges in the longitudinal direction of each of the pressure chambers **310**; in FIG. **16**, the second portion is a circular portion formed of left and right ends of each of the pressure chambers **310**). The electrodes **327**, **328** are circular along the periphery of one of the pressure chambers **310**. Further, electrodes **326**, **329**, **330** are provided to be sandwiched between third to sixth layers **306***c* to **306***f* at a portion **305***a* (hereinafter referred to as "first portion") which is surrounded by the second portion **305***b* and which corresponds to the central portion of each of the pressure chambers **310**. The piezoelectric actuator **306** is firmly fixed to the partition walls **310***c* at portions which are outside of the second portions **305***b* with respect to the first portions **305***a* respectively.

The electrodes **326**, **329**, **330** disposed in the first portion **305***a* configure a first electrode group **331** in which the electrodes face with each other in the stacking direction of the piezoelectric sheets **306***d* to **306***f*. The electrodes **327**, **328**, **326** disposed in the second portion **305***b* configure a second electrode group **333** in which the electrodes face with each other in the stacking direction of the piezoelectric sheets **306***a* to **306***c*. The electrode **326** extends to span across both the first and second portions, and is disposed as a common electrode shared by both of the first and second electrode groups **331**, **333**.

The portions of the piezoelectric sheets **306***b* to **306***e*, sandwiched by the electrodes **326** to **330**, are alternately polarized in the stacking direction (direction of arrows "d") by alternately connecting the electrodes **326** to **330** to the positive power source (+) and ground (G) in the stacking direction as shown in FIG. **17**, and then applying a high voltage for polarization in a publicly known manner. The portions sandwiched by the electrodes **326** to **330** construct active portions **337** to **340** which deform when being applied with a drive voltage. Accordingly, the first portion **305***a* has active portions **339**, **340** in the piezoelectric actuator **306** on a side nearer to the pressure chamber **310** and has the inactive layers **306***a* to **306***c* on the side of the actuator opposite to the pressure chamber. On the other hand, the second portion **305***b* has active portions **337**, **338** in the piezoelectric actuator **306** on the side opposite to the pressure chamber **310** and has the inactive layers **306***d* to **306***f* on the side of the actuator nearer to the pressure chamber.

When, as shown in FIG. **17**, the electrodes **326** to **330** are alternately connected to the positive power source (+) and to ground (G) in the stacking direction in the same manner as during the polarization process, then a drive voltage, which is lower than the polarization voltage, is applied to the electrodes, an electric field that is parallel with the polarization direction "d" is generated in the active portions **337** to **340** so that the active portions **337** to **340** contract in a direction that is perpendicular to the direction in which the piezoelectric sheets are stacked, namely in a direction parallel to the plane of each of the layers. On the other hand, the inactive layers in each of the first and second portions **305***a*, **305***b* do not contract. Accordingly, the first portion **305***a* bends (arches) to project upward, and the second portion **305***b* bends (arches) to project downward, thereby increasing the volume of the pressure chamber **310** as shown in FIG. **18**, as a result of which ink is drawn in from the common ink chamber **315**. Afterward, when the application of voltage to each of the electrodes is stopped, the piezoelectric actuator **306** reverts to its initial flat condition as shown in FIG. **16**. This reverting operation applies pressure to the ink in the pressure chamber **310** so that ink is ejected from the corresponding nozzle **309**. It should be noted that although the active portions **337** to **340** also extend, concurrently with the above-described contracting operation, in the direction parallel to the polarization direction "d", the amount of extension is extremely small as compared to the amount of contraction because there are only a small number of piezoelectric layers in the stack. Therefore, the extension of the active portions hardly influences the ink ejection operation at all.

In this embodiment, if there were no electrodes **327**, **328** in the second portion **305***b* and a voltage is applied only to the electrodes **326**, **329**, **330** in the first portion **305***a* corresponding to a pressure chamber **310***a*, then, as shown in FIG. **19**, the application of voltage to the electrodes in the first portion **305***a* would entirely archingly bend a corresponding portion of the piezoelectric actuator **306** over the pressure chamber **310***a* to project upwardly. Due to the opposite reaction to this operation, as explained in the description of the related art, another portion of the piezoelectric actuator **306**, which corresponds to a pressure chamber **310***b* adjacent to the pressure chamber **310***a*, would archingly bend to project downwardly, with a position above a partition wall **310***c* between the pressure chambers **310***a* and **310***b* being as a fulcrum P**1**. In addition, the partition wall **310***c* between the pressure chambers would also tilt. Namely, the cross talk is generated.

However, in the above-described embodiment, the second portion **305***b* archingly bends to project, at both sides of the first portion **305***a* protrudingly arch, the second portion **305***b* archingly bending in the direction opposite to the direction in which the first portion **305***a* protrudingly arch. This substantially cancels out the opposite reaction associated with deformation of the first portion **305***a*, thereby suppressing the influence to the portion of the piezoelectric actuator **306** corresponding to the adjacent pressure chamber **310***b* and the influence to the partition wall **310***c* between the pressure chambers. Accordingly, cross talk to adjacent pressure chambers is reduced, velocity and volume of ejected ink droplets are made substantially uniform, and printing quality is improved.

Seventh Embodiment

FIGS. **20** and **21** show a seventh embodiment of the present invention. In this embodiment, electrodes **370**, **371**, **372** of the first portion **305***a* are arranged between the layers of the piezoelectric actuator **306** on the side opposite from the pressure chamber **310**, and electrodes **372**, **373** and **374** of the second portion **305***b* are arranged between the layers of the piezoelectric actuator **306** on the side nearer to the pressure chamber **310**. Namely, in the seventh embodiment, the configuration of the piezoelectric actuator **306** is upside down from that of the sixth embodiment. In this case, when voltage is applied to the electrodes **370** to **374**, the first and second portions deform respectively, as shown in FIG. **21**, in a similar manner as in the sixth except that the manner of the deformation of the first and second portions is upside down from that of the sixth embodiment. As a result, the piezoelectric actuator **306** is bent toward the pressure chamber **310**, thereby applying an ejection pressure to the ink.

Eighth Embodiment

FIG. **22** shows an eighth embodiment of the present invention. In this embodiment, a piezoelectric actuator **392** is configured from two layers of piezoelectric sheets **393***a*, **393***b*. An electrode **395**, which is common to both of the layers, is disposed to span across first and second portions **392***a* and **392***b*. An electrode **396**, which faces the center of the common electrode **395**, is provided on an outer surface of the first portion **392***a* in the layer **393***b* (as one of the two layers), and an electrode **394**, which faces the periphery of the common electrode **395**, is provided on an outer surface of the second portion **392***b* of the layer **393***a* (as the other of the two layers). A portion **399** of the first portion **392***a* sandwiched between the electrodes **395**, **396** of the first portion **392***a*, and portions **397**, **398** of the second portion **392***b* sandwiched between the electrodes **394**, **395**, are respectively polarized in a similar manner as in the sixth embodiment.

Then, by applying a drive voltage to the portion between the electrodes **395**, **396** and to the portion between the electrodes **394**, **395**, in each of the first and second portions, the portions interposed between these electrodes contract in the direction perpendicular to the direction in which the layers are stacked, while the portions which are not interposed between electrodes do not contract. Accordingly, in the same manner as in the sixth embodiment, the first portion archingly bends to protrude, while at the same time the second portion archingly bends at both sides of the first portion to protrude in the opposite direction to that of the first portion. In the configuration shown in FIG. **22**, similar to the sixth embodiment, the volume of the pressure chamber **310** is first increased and then the piezoelectric actuator **392** is reverted to the initial state, thereby ejecting the ink. However, the actuator can be configured to reduce the volume of the pressure chamber **310** to eject the ink, similar to the seventh embodiment.

In each of the sixth to eighth embodiments, the electrode in the first portion is added as compared with the first to fifth embodiments, and thus the capacitance is increased by the addition of electrode. However, these embodiments have no electrodes in the inactive portions in the first and second portions as compared with the configuration explained with reference to, for example, FIG. **12**. Accordingly, it is possible to decrease the amounts of capacitance and current for the omitted electrodes in the inactive portions.

Ninth Embodiment

Next, an ink-jet head **100** provided with a piezoelectric actuator **50** of a ninth embodiment will be explained with reference to FIG. **23**. In this embodiment, the cavity plate **10** of the ink-jet head **100** of this embodiment is configured in the same manner as explained in the first and second embodiments.

The actuator **50** of the ninth embodiment has a first portion F and a pair of second portions S corresponding to each of the pressure chambers **16** similar to the embodiments explained above. In the ninth embodiment, the first portion F has electrodes **24**, **25** in the piezoelectric sheets **54** to **56** which are disposed outwardly or farther from one of the pressure chambers **16** in the thickness direction of the piezoelectric actuator. The second portions S have electrodes **24**, **25** in the piezoelectric sheets **51** to **53** which are disposed nearer to the pressure chamber in the thickness direction of the piezoelectric actuator.

In the first portion F, the drive electrodes **24** are disposed between the layers of the piezoelectric sheets **54**, **55**, **56** at positions facing the center of one the pressure chambers **16**. Further, the common electrodes **25** are disposed at both sides of the drive electrodes **24** by a spacing distance in the planar direction of the piezoelectric sheets. In the piezoelectric actuator **50** of the ninth embodiment, the piezoelectric sheets **54**, **55**, **56** in the first portion F are polarized in a direction of P2 shown in FIG. **23**, by applying a high, positive voltage to the drive electrodes **24** and connecting the pairs of common electrodes **25** to ground (GND), each of the pairs being disposed to interpose one of the drive electrodes **24**.

In the second portions S, the drive electrodes **24** are arranged between the layers of the piezoelectric sheets **51**, **52**, **53** in the stack direction of the piezoelectric sheets, along the outer periphery of one of the pressure chambers **16**. The common electrodes **25** are arranged between the layers of the piezoelectric sheets **51**, **52**, **53** in the stacking direction of the piezoelectric sheets, each of the common electrodes **25** being arranged by a spacing distance in the planar direction from one of the drive electrodes **24** toward the inside (toward the center of the associated pressure chamber **16**). The piezoelectric sheets **51**, **52**, **53** are polarized in a planar direction P1 of the piezoelectric sheets by applying a high, positive voltage to the drive electrodes **24** and connecting the common electrodes **25** to ground (GND).

In the piezoelectric actuator **50** provided with the drive electrodes **24** and the common electrodes **25** in this manner, the drive electrodes **24** and the common electrodes **25** are all connected to ground (GND) in the initial condition when the printing operation of the ink-jet printer **101** is to be performed. When, according to predetermined print data, ink is to be ejected from a nozzle **15** communicating with one of the pressure chambers **16**, drive voltage is applied to the drive electrodes **24** while the common electrodes **25** are connected to ground (GND), electric fields E in a direction from the drive electrodes **24** to the common electrodes **25** are generated in each of the first and second portions F, S, the electric fields E coinciding with the direction of polarization P1, P2, respectively, thereby increasing, due to the piezoelectric vertical effect, the distance between the drive electrodes **24** and the common electrodes **25** respectively arranged in the planar direction of the piezoelectric actuator **50**.

At this time, the pair of second portions S is archingly bent, as similar to the second embodiment (FIG. **11**), with its side of the piezoelectric sheets **54** to **56** as the inner direction of the arch, thereby lifting the first portion F in a direction away from the pressure chamber **16**. At the same time, the first portion F is also archingly bent in a direction farther away from the pressure chamber **16**, with its side of pressure chamber **16** as the inner side of the arch. Further, as in the embodiment described above, since the outer periphery of the second portion S is fixed onto the partition walls **14***c*, the volume of the pressure chamber **16** is thus increased. Then, when application of voltage to the drive electrodes **24** is stopped, then the piezoelectric actuator **50** resiliently reverts to its flat condition, thereby applying pressure to the ink in the pressure chamber **16** to eject the ink from the nozzle **15**.

It is needless to say that various modifications or changes may be made or added to the present invention. For example, the drive electrode **24**, the common electrode **25**, the electrodes **327**, **328**, **373**, **374**, **394** may not be formed to have circular shape, but may be arranged as two parallel linear form. Alternatively, among these electrodes, one of the electrodes, facing each other with the piezoelectric sheet intervened therebetween, may be formed in a planar shape across the entire surface of the piezoelectric sheet. Still alternatively, the position of each of the pressure chambers, corresponding to the portion of the piezoelectric actuator to be archingly deformed by the pressure-generating portion, may not be a substantially center of the pressure chamber, but may be a position at which pressure can be applied to the ink in the pressure chamber.

Further, it is needless to say that the piezoelectric actuator **50** of the present invention may not be limited to the use only for an ink-jet head, but also may be employed for transporting various kinds of fluids. In addition, in each of the embodiments, it is configured that the volume of the pressure chamber (fluid accommodating chamber) is increased and then reverted to its initial state, thereby applying pressure to the ink (fluid). However, it is also possible to decrease the volume to apply the pressure. In such a case, the volume can be decreased, for example, by disposing the piezoelectric actuator **50** upside down with respect to the cavity plate **10** in the drawing. Further, in each of the embodiments, the elongating operation of the piezoelectric material can be changed to the contracting operation, thereby decreasing the volume.

Tenth Embodiment

Next, a tenth embodiment of the present invention will be explained. The tenth embodiment is an example in which the present invention is applied to an ink-jet head in which ink is discharged through nozzles. First, an ink-jet printer **600** provided with an ink-jet head **501** will be briefly explained. As shown in FIG. **24**, the ink-jet printer **600** includes a carriage **601** movable in left and right direction in FIG. **24**; a serial-type ink-jet head **501** (liquid transporting apparatus) which is arranged in the carriage **601** and which ejects ink onto a recording paper PA; and feeding rollers **602** which feed the recording paper PA in a forward direction in FIG. **24**, and the like. The ink-jet head **501** moves integrally with the carriage **601** in the left and right direction (scanning direction) and discharges the ink onto the recording paper PA through ejection ports of nozzles **520** (see FIGS. **25** to **28**) which are formed in the ink discharge surface on the lower side of the ink-jet head. The recording paper PA, on which the recording has been performed by the ink-jet head **501**, is discharged in the forward direction (paper feeding direction) by the feeding rollers **602**.

Next, the ink-jet head **501** will be explained. As shown in FIGS. **25** to **28**, the ink-jet head **501** includes a channel unit **502** having ink channels formed therein, and a piezoelectric actuator **503** arranged on the upper surface of the channel unit **502**.

First, the channel unit **502** will be explained. The channel unit **502** includes a cavity plate **501**, a base plate **511**, a manifold plate **512**, and a nozzle plate **513**. These four plates **510** to **513** are stacked and joined together in a laminated state. Among these plates, each of the cavity plate **510**, the base plate **511** and the manifold plate **512** is a stainless steel plate with a substantially rectangular shape. Accordingly, the ink channels such as a manifold **517** and pressure chambers **514** which will be explained later on can be easily formed in the three plates **510** to **512** by means of etching. Further, the nozzle plate **513** is formed of a high-molecular synthetic resin material such as polyimide and is joined to the lower surface of the manifold plate **512**. Alternatively, this nozzle plate **513** may also be formed of a metallic material such as stainless steel similar to the three plates **510** to **512**.

As shown in FIGS. **25** and **26**, a plurality of pressure chambers **514**, arranged and arrayed along a plane, are formed in the cavity plate **510**. These pressure chambers **514** are open upwardly, and covered by a vibration plate **530** which is to be joined to the upper surface of the cavity plate **510** as will be explained later. Each of the pressure chambers **514** is formed to have a substantially elliptic shape which is long in the scanning direction (left and right direction in FIG. **25**) in a plan view, namely as viewed in a direction orthogonal to the plane on which each of the pressure chambers **514** are formed.

In base plate **511**, communication holes **515**, **516** are formed at positions overlapping in a plan view with both ends respectively in the longitudinal direction of one of the pressure chambers **514**. In manifold plate **512**, a manifold **517** is formed. The manifold **517** extends in two rows in the paper feeding direction (up and down direction in FIG. **25**) and overlaps with a portion of each of the pressure chambers **514**, the portion being the side in which the communication hole **515** is formed (right or left portion in each of the pressure chambers **514** in FIG. **25**). To the manifold **517**, ink is supplied from an ink tank (not shown) through an ink supply port **518** formed in the cavity plate **510**. Further, communication holes **519** are formed at positions each of which overlaps in a plan view with an end of one of the pressure chambers **514**, the end being opposite to the manifold **517** (left or light portion, in each of the pressure chambers **514** in FIG. **25**). In the nozzle plate **513**, a plurality of nozzles **520** are formed at positions each of which is overlaps in a plane view with a left or right end of one of the pressure chambers **514** in FIG. **25**. The nozzles **520** are formed, for example, by performing an excimer laser processing on a substrate of high-molecular synthetic resin such as polyimide.

As shown in FIG. **27**, the manifold **517** communicates with the pressure chambers **514** via the communication hole **515**, and the pressure chambers **514** communicate with the nozzles **520** via the communication holes **516**, **519**. Thus, the individual ink channels **521** from the manifold **517** to the nozzles **520** via the pressure chambers **514** are formed in the channel unit **521**.

Next a piezoelectric actuator **503** will be explained. As shown in FIGS. **25** to **28**, the piezoelectric actuator **503** includes an electrically conductive vibration plate **530** disposed on the surface of the channel unit **502**, a piezoelectric layer **531** formed on the upper surface of the vibration plate **530** (surface opposite to the pressure chambers **514**), and a plurality of individual electrodes **532** which are formed on the upper surface of the piezoelectric layer **531** to correspond to the pressure chambers **514** respectively.

The vibration plate **530** is formed of a metallic material (for example, an iron alloy such as stainless steel, a nickel alloy, an aluminum alloy or a titanium alloy) and has a substantially rectangular shape in a plane view. The vibration plate **530** is joined to the cavity plate **510** so as to cover the pressure chambers **514**. The vibration plate **530** also serves as a common electrode which faces the individual electrodes **532** and causes electric field act in the piezoelectric layer **531** between the individual electrodes **532** and the vibration plate **530**. The vibration plate **530** is always maintained at ground potential.

The piezoelectric layer **531** is composed of lead zirconate titanate (PZT) which is a ferroelectric solid solution of lead zirconate and lead titanate. The piezoelectric layer **531** is formed on the upper surface of the vibration plate **530** to entirely cover the plurality of pressure chambers **514**. This piezoelectric layer **531** can be formed, for example, by an aerosol deposition method (AD method) in which particles of a piezoelectric material are ejected and deposited onto an objective surface for layer formation. The piezoelectric layer **531** can be also formed by other known method such as a sputtering method, a CVD (chemical vapor deposition) method, a sol-gel method, or a hydrothermal synthesis method. Alternatively, the piezoelectric layer **531** can be formed by cutting a piezoelectric sheet, obtained by calcinating a green sheet of PZT, into sheets of a predetermined size and then by bonding the cut sheet or sheets to the vibration plate **530**.

Each of the individual electrodes **532** has a circular shape which is long in the scanning direction (left and right direction in FIG. **25**) and in which a hole **532***a* is formed in the central portion of the individual electrode. Further, each of the individual electrodes **532** is formed to surround the central portion of one of the pressure chambers **514** at an area overlapping in a plan view with an edge portion of one of the pressure chambers **514**, the edge portion being other than the central portion of the pressure chamber, such that the hole **532** overlaps in a plane view with the central portion of one of the pressure chambers **514**. The individual electrodes **532** are formed of an electrically conductive material (for example, gold, copper, silver, palladium, platinum or titanium). Further, a plurality of terminals **535** extend in the scanning direction from right or left ends in FIG. **25** of the individual electrodes **532** respectively. These terminals **535** are connected to a driver IC (now shown) via a flexible wiring member (omitted in the drawing) such as a Flexible Printed Circuit (FPC). Drive voltage is selectively supplied from the driver IC to the individual electrodes **532** via the terminals **535** respectively. The individual electrodes **532** and the terminals **535** can be formed by a screen-printing, the sputtering method, an evaporation method, or the like.

Next, the operation of the piezoelectric actuator **503** upon discharging the ink will be explained. When a drive voltage is applied from the driver IC selectively to the plurality of individual electrodes **532**, a potential difference is generated between the individual electrode **532** which is disposed on the piezoelectric layer **531** and to which the drive voltage is applied and the vibration plate **530** as the common electrode which is disposed under the piezoelectric layer **531** and maintained at ground potential, thereby generating an electric field in a vertical direction in a portion of the piezoelectric layer **531** sandwiched between the individual electrode **532** and the vibration plate **530**. Consequently, the portion of the piezoelectric layer **531**, which is positioned directly below the individual electrode **532** applied with the drive voltage, expand in a thickness direction in which the piezoelectric layer **31** is polarized and contract in a direction parallel to the plane of the piezoelectric layer and orthogonal to the polarization direction.

Here, as mentioned above, each of the individual electrodes **532** is formed at the area which overlaps in a plan view with the edge portion of one of the pressure chambers **514**. Accordingly, as shown in FIG. **29**, an area of the piezoelectric actuator **503** overlapping with the edge portion of the pressure chamber **514** becomes a driving zone **A1** in which the piezoelectric layer **531** deforms by itself, and an area overlapping with the central portion of the pressure chamber **514** becomes a driven zone **A2** which is deformed along with the deformation of the piezoelectric layer **531** in the driving zone A1 (zone which is forced to deform). Moreover, an area outside of the pressure chamber **514**, at which the vibration plate **530** is joined to the cavity plate **510**, becomes a constrained zone A3 in which the deformation of the vibration plate **530** is constrained. When the drive voltage is applied to the individual electrode **532**, the piezoelectric layer **531** in the driving zone **A1** on both sides in FIG. **29** is contracted in the direction parallel to the plane, whereas the vibration plate **530** is not contracted in the direction parallel to the plane. Due to this, the vibration plate **530** and the piezoelectric layer **531** of the driven zone A**2** intervened between the driving zones A**1** are deformed. The vibration plate **530** is deformed so as to project toward a side opposite to the pressure chamber **514** with the center of the driven zone A**2** as an apex. As the vibration plate **530** is deformed, a volume inside the pressure chamber **514** increases and a pressure wave is generated in the pressure chamber **514**.

Here, as it is hitherto known, when a time taken by the pressure wave generated due to the increase in the volume of the pressure chamber **514** for one way propagation in the longitudinal direction the pressure chamber **514** is elapsed, the pressure in the pressure chamber **514** is changed to a positive pressure. At this point, at the timing of the change of pressure in the pressure chamber to positive pressure, the driver IC stops applying the drive voltage to the individual electrode **532**. As the driving electrode IC stops applying the driving voltage, the electric potential of the individual electrode **532** becomes the ground potential and the vibration plate **530** restores to the original shape and the volume inside the pressure chamber **514** decreases. At this time, however, the pressure wave generated with the increase in the volume of the pressure chamber **514** mentioned earlier and the pressure wave generated with the restoration of the vibration plate **530** are combined, thereby applying a substantial pressure to the ink in the pressure chamber **514** to discharge the ink from the nozzle **520**. Therefore, by performing a so-called “pulling ejection”, it is possible to apply a high pressure to the ink with a low drive voltage, and accordingly a drive efficiency of the piezoelectric actuator **503** is improved. Moreover, since the electric field is made to act on the piezoelectric layer **531** by applying the drive voltage to the individual electrodes **532** only at a timing of ink discharge, the polarization deterioration hardly occurs in the piezoelectric layer **531**, and accordingly the durability of the actuator is improved.

In view of the driving efficiency, it is desirable that the piezoelectric actuator **503** is configured such that the piezoelectric layer **531** (vibration plate **530**) is greatly deformed with a low drive voltage. The amount of deformation of the vibration plate **530**, however, depends on the size of the individual electrodes **532** to which the drive electrode is applied to cause the electric field act in the piezoelectric layer **531**. Specifically, the amount of deformation is greatly influenced by a length in a radial direction of portions of the individual electrodes **532**, the portions each overlapping with the edge portion of one of the pressure chambers **514**, the radial direction being a direction of a line passing through the area center of one of the pressure chambers **514**. Accordingly, in the piezoelectric actuator **503** of this embodiment, a width direction length A at one side in the width direction orthogonal to the longitudinal direction of the pressure chamber **514** (see FIGS. **26**, **28**; hereinafter referred simply as “width”), is adopted as such a length in the radial direction of the individual electrodes **532**, and the width A of the individual electrodes **532** is set to an optimum value such that a great amount of deformation of the vibration plate **530** can be obtained.

A method for determining the width A of the individual electrodes **532** will be explained. First, when the length of the pressure chambers **514** in the width direction (see FIGS. **26**, **28**; hereinafter referred to simply as “width”) is W, the change of a maximum amount of displacement of the vibration plate **530** (amount of upward displacement at a position facing to the area center of the pressure chamber **514**), when the width A of the individual electrode **532** is changed, is obtained through structural analysis and experimentation using the Finite Element Method (FEM) or the like. For example, FIG. **30** shows a relationship between the maximum amount of deformation of the vibration plate **530** (unit: nm) and a value of A/(W/2) which is a ratio of the width A of the individual electrode **532** to a half of the width W of the pressure chamber **514** (W/2) when the structural analysis using FEM was carried out wherein width W of a pressure chamber **514** is 419 μm, thickness Tv of the vibration plate **530** formed of stainless steel is 20 μm, thickness Tp of the piezoelectric layer **531** formed of PZT is 10 μm, and drive voltage applied to the individual electrode **532** is 20V.

Here, as shown in FIG. **28**, since the piezoelectric layer **531** is formed on the upper surface of the vibration plate **530** so as to entirely cover the pressure chambers **514**, the fluctuation in rigidity of the piezoelectric actuator **503** is small and roughly uniform in the area facing the pressure chambers **514**. Accordingly, when conditions such as the thicknesses and/or elasticities of the vibration plate **530** and piezoelectric layer **531**, or the drive voltage, are changed, the value of the maximum amount of displacement of the vibration plate **530** itself is changed but the tendency of the change in the maximum amount of displacement of the vibration plate **530**, with respect to the width A of the individual electrode **532**, is not changed. For example, in the graph of FIG. **30**, the value of A/(W/2), at which the maximum amount of displacement of the vibration plate **530** becomes the peak value, does not depend on other conditions such as the thicknesses of the vibration plate **530** and the piezoelectric layer **531** or the drive voltage. In this case, as the maximum amount of the displacement of the vibration plate **530** is greater, the pressure to be applied to the ink in the pressure chamber **514** becomes greater with the same drive voltage. Accordingly, an optimum value of A/(W/2) is a value at which the maximum amount of displacement of the vibration plate **530** becomes the peak value (5.5), and the optimum value for the width A of the individual electrode **532** can be easily determined.

The width A of the individual electrodes **532**, actually formed on the upper surface of the piezoelectric layer **531**, deviates from the above-described optimum value in some cases due to the manufacturing error. In such a case, consequently, the maximum amount of displacement of the vibration plate **530** may vary among the pressure chambers **514**, due to which the droplet velocity of the ink droplet discharged from the nozzles may vary among the plurality of nozzles **520**. If the variation in the droplet velocity is great, the printing quality is deteriorated in some cases as a result. The inventor conducted experiments to discover the following relationship between the amount of displacement of the vibration plate **530** and the velocity of ink droplet discharged from the nozzle **520**. According to this relationship, as shown in FIG. **31**, when the amount of displacement of the vibration plate **530** is reduced by 7.5%, the velocity of droplet is reduced by 1 m/s. In piezoelectric actuators **503** of different types, although curves showing the relationship between the amount of displacement of the vibration plate **530** and the velocity of droplet are different as curve “a” and curve “b” in FIG. **31**, this relationship itself holds for any type of piezoelectric actuator **503**. In view of this, when the value of width A of the individual electrode deviates from the optimum value, the range of A, which is acceptable, is determined as follows.

In order to maintain a good print quality, it is desirable that the variation in the velocity of droplet is suppressed to be at least not more than 2 m/s. For this purpose, from the relationship shown in FIG. **31**, it is necessary to suppress the variation in the maximum amount of displacement of the vibration plate **530** to be not more than 15%. Accordingly, it is desirable that the value of A/(W/2) falls within a range in which a value of 0.55, at which the maximum amount of displacement becomes the peak value, is intervened and in which the maximum amount of displacement is −15% with respect to the peak value, namely, within a range of not less than 0.33 to not more than 0.75 from the relationship shown in FIG. **30**, such that the maximum amount of displacement of the vibration plate **530** is as great at possible and that the tolerance for the width A of the individual electrode **532** is broad.

Moreover, to maintain even better print quality, it is necessary in some cases to suppress the variation in the velocity of droplet to be not more than 1 m/s. In this case, it is desirable that the value of A/(W/2) falls within a range in which the value of 0.55, at which the maximum amount of displacement becomes the peak value, is intervened and in which the maximum amount of displacement is −7.5% with respect to the peak value, namely, within a range of not less than 0.41 to not more than 0.69 from the relationship shown in FIG. **30**.

Further, when the value of width A of individual electrodes **532** is small, the capacitance generated in the piezoelectric layer **531** sandwiched between the individual electrodes **532** and the vibration plate **530** becomes smaller than a case in which the value of A is great, and thus the electric power consumed by the piezoelectric actuator **503** becomes small. Accordingly, it is desirable that the value of A/(W/2) falls in a range of not more than 0.55, at which the maximum amount of displacement is the peak value, and not less than 0.41.

Next, a method of producing the ink-jet head **501** will be explained.

First of all, as shown in FIG. **32**A, four metal plates of a cavity plate **510**, a base plate **511**, a manifold plate **512**, in which holes which are to form the pressure chambers **514** and manifold **517** or the like are formed, and the vibration plate **530** are joined together. Then, as shown in FIG. **32**B, the piezoelectric layer **531** is formed on the upper surface of the vibration plate **530** by means of the AD method or the like, such that the piezoelectric layer **531** covers the plurality of pressure chambers **514** (piezoelectric layer formation step).

Next, based on the relationship between the value of A/(W/2) and the amount of deformation (maximum amount of deformation) of the vibration plate **530** when a voltage is applied to the individual electrode **532**, as shown in FIG. **30**, a value of width A of the individual electrode **532** is determined such that the maximum amount of displacement of the vibration plate **530** becomes the peak value (namely, value of A/(W/2) is 0.55) (electrode length determination step). Then, as shown in FIG. **32**C, the individual electrodes **532** having the determined value of A are formed, by means of screen-printing or the like, on the upper surface of the piezoelectric layer **531** at areas each of which overlaps with an edge portion of one of the pressure chambers **514** (individual electrode formation step). At this time, terminals **532** connected to the individual electrodes **532** respectively are simultaneously formed. Finally, as shown in FIG. **32**D, a nozzle plate **513** is joined to the lower surface of the manifold plate **512**, and thus the production of the ink-jet head **501** is completed.

It should be noted that the width A of the individual electrode **532** may be determined based on the relationship of FIG. **30** before the joining of the four metal plate of the cavity plate **510**, the base plate **511**, the manifold plate **512** and the vibration plate **530**.

Further, when the nozzle plate **513** is a metal plate, this nozzle plate **513** may be also joined simultaneously with the other four metal plates (cavity plate **510**, base plate **511**, manifold plate **512** and vibration plate **530**).

According to the method for producing the ink-jet head **501** of the tenth embodiment, the following effects can be obtained. Namely, since the individual electrodes **532** are formed at the areas each of which overlaps with the edge portion of one of the pressure chambers **514**, the edge portion being an area other than the central portion of the pressure chamber, and the pulling ejection can be realized by applying the drive voltage to the individual electrodes **532** only at the timing when the ink is discharged. Accordingly, the drive efficiency of the piezoelectric actuator **503** is enhanced and the durability of the actuator is excellent. In addition, the width A of the individual electrodes **532** has a value such that the maximum amount of displacement of the vibration plate **530** is as great as possible within a range in which the variation in the droplet velocity can be suppressed and the satisfactory printing quality can be maintained. Accordingly, the drive efficiency of the piezoelectric actuator **503** is further improved.

Next, an explanation will be given about modified embodiments in which various changes are made to the tenth embodiment. Here, elements or components of the modified embodiments having the same configuration as those of the tenth embodiment are given the same reference numerals and the descriptions therefore are omitted as appropriate.

[1] When the vibration plate is formed of an insulation material (for example, a silicon material in which a surface thereof is subjected to oxidation processing, a PZT material which is same as that for the piezoelectric layer **531**, a ceramic material such as alumina or zirconia, or a synthetic resin material such as polyimide) (First Modified Embodiment). In this case, however, in a piezoelectric actuator **503**A as shown in FIG. **33**, a common electrode **534** is required on a surface of the insulative vibration plate **530**A on a side opposite to the pressure chambers **514**, such that the common electrode **534** is opposed to the individual electrodes **532** to generate an electric field in the piezoelectric layer **531** between the individual electrodes **532** and the common electrode **534**.

[2] In the tenth embodiment, the individual electrodes are arranged on the piezoelectric layer **531** on the side opposite to the vibration plate **530**. However, the individual electrodes may be arranged on the piezoelectric layer **531** on the side of the vibration plate **530**, and the common electrode **534** may be arranged on the piezoelectric layer **531** on the side opposite to the vibration plate **530**. In this case, however, when the vibration plate is formed of a metallic material, in a piezoelectric actuator **503**B as shown in FIG. **34**, it is necessary that the upper surface of the metallic vibration plate **530**, where individual electrodes **530**B are to be arranged, is made to be insulative, for example, by forming an insulating material layer **540** on the upper surface (surface opposite to the pressure chambers **514**) of the metallic vibration plate **530**, so that the individual electrodes **532**B are insulated from one another (Second Modified Embodiment). This insulating material layer **540** can be formed of a ceramic material such as alumina or zirconia by using the AD method, the sputtering method, the CVD method or the sol-gel method, or the like.

On the other hand, when the vibration plate is formed of an insulation material such as a silicon material, PZT which is the same material of which the piezoelectric layer **531** is formed, a ceramic material such as alumina or zirconia, or a synthetic resin material or the like, then as shown in FIG. **35**, it is sufficient in a piezoelectric actuator **503**C that the individual electrodes **532** are directly arranged on the upper surface of a vibration plate **530**. Accordingly, the individual electrodes **532** are insulated from one another by the insulative vibration plate **530**. (Third Modified Embodiment)

[3] Each of the individual electrodes **532** does not have to be formed in an annular shape to surround the central portion of one of the pressure chambers **514** as in the above-described tenth embodiment. For example, as shown in FIG. **36**, it is allowable that each of individual electrodes **532**D does not completely surround the central portion of one of the pressure chambers **514** (Fourth Modified Embodiment). Here, in order to increase the amount of deformation of the vibration plate **530**, it is desirable that each of the individual electrodes **532**D is formed at least at two areas **550** which are included in the area overlapping with the edge portion of one of the pressure chambers **514**, the two areas extending substantially parallel to the longitudinal direction (left and right direction in FIG. **36**) of one of the pressure chambers **514**. In this case, similar to the above-described tenth embodiment, the value of the width A of the portion of the individual electrode **532**D formed in this area **550**, is determined to be a value such that the amount of deformation of the vibration plate **530** becomes great.

[4] The shape of the pressure chambers is not limited to a substantially elliptic shape as in the abovementioned embodiment, and the pressure chambers may be formed in other shapes such as a circular shape, a rhombus, or a rectangular shape or the like (Fifth Modified Embodiment). For example, as shown in FIG. **37**, when the shape of pressure chamber is circular, the length A in the radial direction (direction of a line passing through the center C of the surface area of a pressure chamber **514**E) of an individual electrode **532**E is determined to be an optimum value such that the maximum displacement of the vibration plate **530** becomes great.

Eleventh Embodiment

Next, an eleventh embodiment of the present invention will be explained. The eleventh embodiment is also an example in which the present invention is applied to an ink-jet head, and is similar to the tenth embodiment except for the configuration of the piezoelectric actuator. Here, elements or components of the eleventh embodiment having the same configuration as those of the tenth embodiment are given the same reference numerals and the descriptions therefore are omitted as appropriate.

As shown in FIGS. **38** and **39**, a piezoelectric actuator **563** of an ink-jet head **561** of this eleventh embodiment includes an electrically conductive vibration plate **530** arranged on the surface of a channel unit **502**, a piezoelectric layer **571** formed on the upper surface of the vibration plate **530** (side opposite to a plurality of pressure chambers **514**), and a plurality of individual electrodes **572** formed on the upper surface of the piezoelectric layer **571** corresponding to the pressure chambers **514** respectively.

Here, the piezoelectric actuator **563** of the eleventh embodiment is different from the piezoelectric actuator **503** (see FIGS. **27** to **29**) of the tenth embodiment in that the piezoelectric layer **571** is formed on the upper surface of the vibration plate **530** at areas each of which overlaps in a plane view with the edge portion of one of the pressure chambers **514**. On the other hand, openings **571** are formed at areas each of which overlaps with the central portion of one of the pressure chambers **514**, and the openings **571** are areas in which the piezoelectric layer **571** is not partially formed.

Further, similar to the tenth embodiment, a length in the width direction (left and right direction in FIG. **39**) of the individual electrode **572**, the width direction being a direction orthogonal to the longitudinal direction of the pressure chamber **514**, is set to be an optimum value such that the amount of deformation (maximum amount of displacement) of the vibration plate **530** becomes great.

Similar to the tenth embodiment, FIG. **40** shows a relationship between the maximum amount of displacement of the vibration plate **530** and a value of A/(W/2) which is a ratio of the width A of the individual electrode **572** to a half of the width W of the pressure chamber **514** (W/2) when the structural analysis using FEM was carried out wherein width W of pressure chamber **514** is 419 μm, thickness Tv of the vibration plate **530** formed of stainless steel is 20 μm, thickness Tp of the piezoelectric layer **571** formed of PZT is 10 μm, and drive voltage applied to the individual electrode **532** is 20V. Accordingly, an optimum value of A/(W/2) is set to 0.44 which is a value at which the maximum amount of displacement of the vibration plate **530** becomes the peak value, and the optimum value for the width A of the individual electrode **532** is determined from this value. It should be noted that in the piezoelectric actuator **563** of the eleventh embodiment, the driven zones of the piezoelectric actuator **563**, each of which overlaps with the central portion of one of the pressure chambers **514**, is constructed only of the vibration plate **530**. Accordingly, the rigidity of the driven zones becomes small, and consequently the maximum amount of displacement of the vibration plate **530** as a whole becomes greater than in the piezoelectric actuator **503** of the tenth embodiment (see FIGS. **27** to **29**).

The width A of the individual electrodes **532** actually formed deviates in some cases from the above-described optimum value due to the manufacturing error. In such a case, for example, a range of the value A, which is acceptable, is determined as follows. When the variation in the velocity of droplet needs to be suppressed to be within a range of not more than 2 m/s, then, according to the empirical rule that when the maximum amount of displacement of the vibration plate **530** is reduced by 7.5%, the velocity of droplet is reduced by 1 m/s (see FIG. **31**), the value of A/(W/2) may be in a range of not less than 0.27 and not more than 0.63 in which the maximum amount of displacement of the vibration plate **530** is within −15% of the peak value. Further, when the variation in the velocity of droplet needs to be suppressed in a more stringent range of not more than 1 m/s, then the value of A/(W/2) may be in a range of not less than 0.33 and not more than 0.56 in which the maximum amount of displacement of the vibration plate **530** is within −7.5% of the peak value.

In the piezoelectric actuator **563** of the eleventh embodiment, the piezoelectric layer **571** is formed on the upper surface of the vibration plate **530** at areas each of which overlaps with the edge portion of one of the pressure chambers **514**, but the piezoelectric layer **571** is not formed on the upper surface of the vibration plate **530** at areas each of which overlaps with the central portion of one of the pressure chambers **514**. Accordingly, there is a difference in the rigidity between these two kinds of areas. Since the rigidity in each of the two kinds of areas depends on the thickness Tv of vibration plate **530**, the thickness Tp of piezoelectric layer **571** and a width S of opening **575**, when any one of the three parameters Tv, Tp and S changes, there is a change in the tendency of the maximum amount of displacement, of the vibration plate **530**, with respect to the width A of the individual electrode **572**. Accordingly, the relationship between the value of A/(W/2) and the maximum amount of displacement of the vibration plate **530** as shown in FIG. **40** is determined in advance for each combination of the three parameters Tv, Tp and S, and then one relationship, which is included in the determined relationships between the value of A/(W/2) and the maximum amount of displacement of the vibration plate

530 and which corresponds to the values of Tv, Tp and S measured in the step of manufacturing the ink-jet head **561**, is selected to determine an optimum value of A/(W/2) from the selected relationship. In the following, FIGS. **41** to **43** respectively show a tendency of change in the relationship between the value of A/(W/2) and the maximum amount of displacement of the vibration plate **530** when one of the thickness Tv of vibration plate **530**, the thickness Tp of piezoelectric layer **571**, and the width S of opening **575** is changed.

As shown in FIG. **41**, when the thickness Tv of the vibration plate **530** becomes great, the value of A/(W/2) at which the maximum amount of displacement peaks becomes great. On the other hand, when Tv becomes small, the value of A/(W/2) at which the maximum amount of displacement peaks becomes small. As shown in FIG. **42**, when the thickness Tp of the piezoelectric layer **571** becomes great, the value of A/(W/2) at which the maximum amount of displacement peaks becomes small. On the other hand, when Tp becomes small, the value of A/(W/2) at which the maximum amount of displacement peaks becomes great. Further, as shown in FIG. **43**, when the width S of the opening **575** becomes great, the value of A/(W/2) at which the maximum amount of displacement peaks becomes small. On the other hand, when S becomes small, the value of A/(W/2) at which the maximum amount of displacement peaks becomes great.

In the following, a method for producing the ink-jet head **561** of the eleventh embodiment will be explained. First, the relationship between the value of A/(W/2) and the maximum amount of displacement of the vibration plate **530** as shown in FIG. **40** is determined for each combination of the thickness Tv of the vibration plate **530**, the thickness Tp of the piezoelectric layer **571**, and the width S of the opening **575**.

Next, as shown in FIG. **44**A, the thickness Tv of the vibration plate **530** is measured (step for measuring the thickness of the vibration plate **530**), and then the four metal plate of the cavity plate **510**, the base plate **511**, the manifold plate **512** and the vibration plate **530** are joined altogether. Subsequently, as shown in FIG. **44**B, the piezoelectric layer **571** is formed on the upper surface of the vibration plate **530** at areas each of which overlaps with the edge portion of one of a plurality of pressure chambers **514** by means of the AD method or the like, such that the plurality of openings **575** are formed at locations each of which overlaps with the central portion of one of the pressure chambers **514** (piezoelectric layer formation step). Then, the thickness Tp of the piezoelectric layer **571** is measured by using a laser displacement gauge or the like (step of measuring the thickness of the piezoelectric layer), followed by measuring the width S of the openings **575** each of which is formed at an area overlapping with the central portion of one of the pressure chambers **514** (opening length measurement step).

Next, one relationship between the value of A/(W/2) and the maximum amount of displacement of the vibration plate **530**, corresponding to the measured values of Tv, Tp and S, is selected from the relationships between the value of A/(W/2) and the maximum amount of displacement of the vibration plate **530** determined in advance for each of the combinations of the thickness Tv of the vibration plate **530**, the thickness Tp of the piezoelectric layer **571** and the width S of the opening **575**. Then, the width A of the individual electrodes **572** is determined based on the selected relationship such that the maximum amount of displacement of the vibration plate **530** becomes great (individual electrode length determination step). Next, as shown in FIG. **44**C, the individual electrodes **571** having the determined value A are formed, with the screen-printing or the like, on the upper surface of the piezoelectric layer **571** at the areas each of which overlapping with the edge portion of one of the pressure chambers **514** (individual electrode formation step). Finally, as shown in FIG. **44**D, the nozzle plate **513** is joined to the lower surface of the manifold plate **512**, thus completing the production of the ink-jet head **561**.

According to the method for producing the ink-jet head **561** of the eleventh embodiment, similar to the tenth embodiment, the width A of the individual electrodes **532** can be a value such that the maximum amount of displacement of the vibration plate **530** becomes great in a range not adversely affecting the printing quality. Accordingly, the drive efficiency of the piezoelectric actuator **563** is further improved. Further, the driven zones in the piezoelectric actuator **563**, each of which overlaps with the central portion of one of the pressure chambers **514**, are constructed only with the vibration plate **530**. Accordingly, the rigidity in the driven zones becomes small, and thus the maximum amount of displacement of the vibration plate **530** becomes greater than in the piezoelectric actuator **503** of the tenth embodiment (see FIGS. **27** to **29**).

It should be noted that also in the eleventh embodiment, each of the individual electrodes does not have to be formed in an annular shape to surround the central portion of one of the pressure chambers. For example, as the fourth modification of the tenth embodiment (see FIG. **36**), it is allowable that each of individual electrodes does not completely surround the central portion of one of the pressure chambers. Further, the shape of the pressure chambers is not limited to a substantially elliptic shape, and the pressure chambers may be formed in other shapes such as, a circular shape, a rhombus, or a rectangular shape or the like.

Each of the above-explained tenth and eleventh embodiments is an example in which the present invention is applied to an ink-jet head which transports ink to the nozzles to discharge the ink through the nozzles. However, the liquid transporting apparatus, to which the present invention is applicable, is not limited to the ink-jet head. For example, the present invention can also be applied to a liquid transporting apparatus which transports a liquid such as a medicinal solution or a biochemical solution inside a micro total-analyzing system (μTAS), a liquid transporting apparatus which transports a liquid such as a solvent and a chemical solution inside a micro chemical system, and a liquid transporting apparatus which transports a liquid other than ink.

Twelfth Embodiment

Next, a twelfth embodiment of the present invention will be explained. In an ink-jet head **700** as the liquid transporting apparatus of the present invention, an actuator **750** includes a metal layer **751** and a piezoelectric layer **752**, as shown in FIG. **45**A. A plurality of operation portions O is provided in the piezoelectric layer **752** in one-to-one correspondence with the pressure chambers **16** respectively. In each of second portions S in each of the operation portions O, an electrode **753** is provided over the piezoelectric layer **752**. An active portion **740** is formed between the electrode **753** and the metal layer **751** when a high, polarizing voltage is applied between the electrode **753** and the metal layer **751**. In this embodiment, a cavity plate **710** makes contact with a surface of the metal layer **751**. However, the cavity plate **750** may make contact with a surface of the piezoelectric layer **752**.

Similarly, as shown in FIG. **45**B, the piezoelectric actuator **750** may be provided with an insulation layer **754** and the piezoelectric layer **752**. The insulation layer **754** is formed of ceramic or resin. A plurality of operation portions O is provided in the piezoelectric layer **752** in one-to-one correspondence with the pressure chambers **16**. In each of second portions S in each of the operation portions O, a pair of electrodes **755** is provided such that one electrode **755** of the pair is disposed over the piezoelectric layer **752** and the other electrode **755** of the pair is disposed over the insulation layer **754**. An active portion **740** is formed between the pair of electrodes **755** when a high, polarizing voltage is applied between the electrodes **755** of the pair. In this embodiment, although the cavity plate **710** makes contact with a surface of the insulation layer **754**, the cavity plate **710** may make contact with a surface of the piezoelectric layer **752**.

Thirteenth Embodiment

Next, a thirteenth embodiment of the present invention will be explained. In an ink-jet head **700** as the liquid transporting apparatus of the present invention, the piezoelectric layer is not a single layer but is individually provided for each of the plurality of operation portions O. As shown in FIG. **46**A, the plurality of operation portions O, each of which is formed of a piezoelectric material, may be formed individually from one another. The operation portions O are arranged in the planar direction over the metal layer **751** separately from one another in the planar direction. The electrode **753** is provided over each of the second portions S in each of the operation portions O so as to form an active portion between the electrode **753** and the metal layer **751**. Here, although the cavity plate **710** makes contact with a surface of the metal layer **751**, the cavity plate **710** may make contact with upper surfaces of the plurality of operation portions O.

As shown in FIG. **46**B, in a piezoelectric actuator **750** having an insulation layer **754** which is formed of ceramic or resin, a plurality of operation portions O, each of which is made of piezoelectric material, may be formed individually from one another. The plurality of piezoelectric operation portions O are arranged in the planar direction over the insulation layer **754** separately from one another in the planar direction. A pair of electrodes **755** is provided in each of second portions S of each of the operation portion O such that the pair of the electrodes **755** sandwiches each of the second portions S therebetween in each of the operation portions O to form an active portion **740**. In this embodiment, although the cavity plate **710** makes contact with a surface of the insulation layer **754**, the cavity plate **710** may make contact with surfaces of the plurality of piezoelectric active portions O.

What is claimed is:

1. A liquid transporting apparatus comprising:

a plate-shaped body including first and second surfaces which are separated from each other by a predetermined distance in a thickness direction and which extend in a predetermined planar direction substantially perpendicular to the thickness direction, and an operation portion having a first portion and a pair of second portions disposed symmetrically on either side of the first portion with respect to the planar direction;

at least one electrode located in each of the second portions, the at least one electrode including at least one pair of electrodes to sandwich an active portion, the active portion being defined in each of the second portions between the pair of electrodes and located nearer to the first surface than the second surface in the thickness direction, at least the active portion in the plate-shaped body being formed from piezoelectric material, the at least one pair of electrodes generating an electric field for deforming the active portion in the planar direction, thereby archingly deforming each of the second portions in a direction from one to the other of the first and second portions, and consequently archingly deforming the first portion in an opposite direction from the other to the one of the first and second portions, thereby deforming the operation portion in the thickness direction;

a fluid accommodating plate disposed to face one of the first surface and the second surface of the plate-shaped body, the fluid accommodating plate forming a fluid accommodating chamber, the operation portion of the plate-shaped body confronting the fluid accommodating chamber, volume of the fluid accommodation chamber changing in association with the deformation of the first portion and of the pair of second portions to transport fluid in the fluid accommodation chamber;

a hole-defining portion defining an ejection hole in fluid communication with the fluid accommodating chamber, change in volume of the fluid accommodation chamber transporting the fluid in the fluid accommodation chamber through the ejection hole;

wherein a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the fluid accommodating chamber, and A is a length in the radial direction of a portion of the at least one electrode, the portion being formed at an area which overlaps with one side portion in the radial direction of the at least one electrode and an edge portion of the fluid accommodating chamber, the edge portion being other than a central portion of the fluid accommodating chamber.

2. The liquid transporting apparatus according to claim **1**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.69.

3. The liquid transporting apparatus according to claim **1**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.55.

4. The liquid transporting apparatus according to claim **1**, wherein the fluid accommodating chamber has a shape long in a predetermined direction; and

the at least one electrode is formed at two areas which are included in the area overlapping with the edge portion of the fluid accommodating chamber and which extend substantially in parallel in the predetermined direction.

5. The liquid transporting apparatus according to claim **1**,

wherein the pair of electrodes in each of the second portions are disposed in confrontation with each other to sandwich the active portion therebetween in a predetermined direction, the predetermined direction being either one of the planar direction and the thickness direction, the active portion being polarized in a direction parallel to the predetermined direction, the electric field generated between the confronting electrodes in the predetermined direction changing a length of the active portion in the planar direction, thereby bending the corresponding second portions in the direction from one to the other of the first surface and the second surface, and consequently bending the first portion in the opposite direction from the other to the one of the first surface and the second surface, thereby deforming the operation portion in the thickness direction;

wherein the plate-shaped body includes a piezoelectric layer which is formed of a piezoelectric material and which defines the first surface, and the pair of electrodes which is formed to sandwich the piezoelectric layer therebetween to define the active portion in the piezoelectric layer sandwiched between the electrodes;

wherein the pair of electrodes in each of the second portions includes a first surface electrode and a second surface electrode, the first surface electrode being disposed on the first surface, the second surface electrode of the pair of electrodes in each of the pair of second portions being integrated with a metal layer formed of metal, and the metal layer defining the second surface on a surface of the metal layer opposite to the other surface thereof facing the piezoelectric layer; and

wherein the active portion is defined in each of the second portions at a location between the first surface electrode and the second surface electrode, the first surface electrode and the second surface electrode generating the electric field for deforming the active portion in the planar direction.

6. The liquid transporting apparatus according to claim **1**, wherein the pair of electrodes in each of the second portions are disposed in confrontation with each other to sandwich the active portion therebetween in a predetermined direction, the predetermined direction being either one of the planar direction and the thickness direction, the active portion being polarized in a direction parallel to the predetermined direction, the electric field generated between the confronting electrodes in the predetermined direction changing a length of the active portion in the planar direction, thereby bending the corresponding second portions in the direction from one to the other of the first surface and the second surface, and consequently bending the first portion in the opposite direction from the other to the one of the first surface and the second surface, thereby deforming the operation portion in the thickness direction;

wherein the plate-shaped body includes a plurality of operation portions made of a plurality of piezoelectric material portions, the piezoelectric material portions being arranged in the planar direction separately from one another in the planar direction, the piezoelectric material portions defining the first surface;

wherein the pair of electrodes in each of the second portions includes a first surface electrode and a second surface electrode, the first surface electrode being disposed on the first surface, the second surface electrode of the pair of electrode in each of the pair of second portions being integrated with a metal layer formed of metal, and the metal layer defining the second surface on a surface of the metal layer opposite to the other surface thereof facing the piezoelectric material portions; and

wherein the active portion is defined in each of the second portions at a location between the first surface electrode and the second surface electrode, the first surface electrode and the second surface electrode generating the electric field for deforming the active portion in the planar direction.

7. A liquid transporting apparatus comprising:

a channel unit having a plurality of pressure chambers each of which is arranged along a plane; and

a piezoelectric actuator which selectively changes volumes of the pressure chambers to apply pressure to a liquid in the pressure chambers;

wherein the piezoelectric actuator includes:

a vibration plate joined to the channel unit to cover the pressure chambers;

a piezoelectric layer which is arranged on a side of the vibration plate opposite to the pressure chambers and which is formed to overlap with the pressure chambers as viewed in a direction perpendicular to the plane;

a plurality of individual electrodes each of which is formed at an area of the piezoelectric layer, the area being in one surface of the piezoelectric layer and overlapping with an edge portion of one of the pressure chambers as viewed in the direction perpendicular to the plane, the edge portion being other than a central portion of one of the pressure chambers; and

a common electrode which is formed on the other surface of the piezoelectric layer;

wherein a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the pressure chambers, and A is a length of portions of the individual electrodes in the radial direction, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers.

8. The liquid transporting apparatus according to claim **7**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.69.

9. The liquid transporting apparatus according to claim **7**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.55.

10. The liquid transporting apparatus according to claim **7**, wherein each of the pressure chambers has a shape long in a predetermined direction; and

each of the individual electrodes is formed at least at two areas which are included in the area overlapping with the edge portion of one of the pressure chambers and which extend substantially in parallel to the predetermined direction.

11. The liquid transporting apparatus according to claim **7**, wherein the vibration plate is formed of a metallic material and serves as the common electrode.

12. The liquid transporting apparatus according to claim **7**, wherein the vibration plate is insulative at least on a surface of the vibration plate opposite to the pressure chambers; and

the common electrode is formed on the surface of the vibration plate opposite to the pressure chambers.

13. The liquid transporting apparatus according to claim **7**, wherein the vibration plate is insulative at least on a surface of the vibration plate opposite to the pressure chambers; and

the individual electrodes are formed on the surface of the vibration plate opposite to the pressure chambers.

14. The liquid transporting apparatus according to claim **7**,

wherein the piezoelectric layer is formed to overlap entirely with the pressure chambers as view of in the direction perpendicular to the plane.

15. A method for producing a liquid transporting apparatus provided with a channel unit having a plurality of pressure chambers each of which is arranged along a plane; and a piezoelectric actuator including a vibration plate which covers the pressure chambers, a piezoelectric layer arranged on a side of the vibration plate opposite to the pressure chambers, a plurality of individual electrodes each of which is formed at an area of the piezoelectric layer, the area being in one surface of the piezoelectric layer and overlapping with an edge portion of one of the pressure chambers as viewed in a direction perpendicular to the plane, the edge portion being other than a central portion of one of the pressure chambers, and a common electrode which is formed on the other surface of the piezoelectric layer, the method comprising:

an electrode length determination step of determining a length A in a radial direction of the individual electrodes based on a relationship between an amount of deformation of the vibration plate when a voltage is applied to the individual electrodes and a value of A/(W/2) in which W is a length in the radial direction of the pressure chambers, and A is a length in the radial direction of portions of the individual electrodes, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers; and

an individual electrode formation step of forming the individual electrodes having the length A determined in the electrode length determination step.

16. The method according to claim **15**, comprising a piezoelectric layer formation step of forming the piezoelectric layer so as to entirely cover the pressure chambers.

17. The method according to claim **15**, comprising:

a vibration plate thickness measurement step of measuring a thickness of the vibration plate;

a piezoelectric layer formation step of forming the piezoelectric layer at areas on a surface of the vibration plate opposite to the pressure chambers, each of the areas overlapping with the edge portion of one of the pressure chambers, such that a plurality of openings are formed at locations overlapping with central portions of the pressure chambers respectively as viewed in the direction perpendicular to the plane;

a piezoelectric layer thickness measurement step of measuring a thickness of the piezoelectric layer; and

an opening length measurement step of measuring a length in the radial direction of the openings, each of the openings overlapping with one of the pressure chambers and being an area in which the piezoelectric layer is partially absent as viewed in the direction perpendicular to the plane,

wherein in the electrode length determination step, the relationship between the amount of deformation of the vibration plate when the voltage is applied to the individual electrodes and the value of A/(W/2) is determined based on the thickness of the vibration plate, the thickness of the piezoelectric layer, and the length in the radial direction of the openings; and the length A in the radial direction of the individual electrodes is determined based on the determined relationship.

18. A liquid transporting apparatus comprising:

a plate-shaped body including first and second surfaces which are separated from each other by a predetermined distance in a thickness direction and which extend in a predetermined planar direction substantially perpendicular to the thickness direction, and an operation portion having a first portion and a pair of second portions disposed symmetrically on either side of the first portion with respect to the planar direction;

at least one electrode located in each of the second portions, the at least one electrode including at least one pair of electrodes to sandwich an active portion, the active portion being defined in each of the second portions between the pair of electrodes and located nearer to the first surface than the second surface in the thickness direction, at least the active portion in the plate-shaped body being formed from piezoelectric material, the at least one pair of electrodes generating an electric field for deforming the active portion in the planar direction, thereby archingly deforming each of the second portions in a direction from one to the other of the first and second portions, and consequently archingly deforming the first portion in an opposite direction from the other to the one of the first and second portions, thereby deforming the operation portion in the thickness direction;

a fluid accommodating plate disposed to face one of the first surface and the second surface of the plateshaped body, the fluid accommodating plate forming a fluid accommodating chamber, the operation portion of the plateshaped body confronting the fluid accommodating chamber, volume of the fluid accommodation chamber changing in association with the deformation of the first portion and of the pair of second portions to transport fluid in the fluid accommodation chamber;

a hole-defining portion defining an ejection hole in fluid communication with the fluid accommodating chamber, change in volume of the fluid accommodation chamber transporting the fluid in the fluid accommodation chamber through the ejection hole;

wherein a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the fluid accommodating chamber, and A is a length in the radial, direction of a portion of the piezoelectric material, the portion being formed at an area which overlaps with one side portion in the radial direction of the active portion and an edge portion of the fluid accommodating chamber, the edge portion being other than a central portion of the fluid accommodating chamber.

19. The liquid transporting apparatus according to claim **18**, wherein the value of A/(W/2) is not less than 0.41 and not mare than 0.69.

20. The liquid transporting apparatus according to claim **18**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.55.

21. The liquid transporting apparatus according to claim **18**, wherein the fluid accommodating chamber has a shape long in a predetermined direction; and

wherein the at least one electrode is formed at two areas which are included in the area overlapping with the edge portion of the fluid accommodating chamber and which extend substantially in parallel in the predetermined direction.

22. A liquid transporting apparatus comprising:

a channel unit having a plurality of pressure chambers each of which is arranged along a plane; and

a piezoelectric actuator which selectively changes volumes of the pressure chambers to apply pressure to a liquid in the pressure chambers;

wherein the piezoelectric actuator includes:

a vibration plate joined to the channel unit to cover the pressure chambers;

a piezoelectric layer which is arranged on a side of the vibration plate opposite to the pressure chambers and which is formed to overlap with the pressure chambers as viewed in a direction perpendicular to the plane;

a plurality of individual electrodes each of which is formed at an area of the piezoelectric layer, the area being in one surface of the piezoelectric layer and overlapping with an edge portion of one of the pressure chambers as viewed in the direction perpendicular to the plane, the edge portion being other than a central portion of one of the pressure chambers; and

a common electrode which is formed on the other surface of the piezoelectric layer; wherein the piezoelectric layer has driving zones each of which is provided between the common electrode and one of the individual electrodes and deforms by itself when a drive voltage is applied to the one of the individual electrodes, a value of A/(W/2) is not less than 0.33 and not more than 0.75 when W is a length in a radial direction of the pressure chambers, and A is a length of portions of the driving zones in the radial direction, the portions being formed at areas each overlapping with one side portion, in the radial direction, of the edge portion of one of the pressure chambers.

23. The liquid transporting apparatus according to claim **22**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.69.

24. The liquid transporting apparatus according to claim **22**, wherein the value of A/(W/2) is not less than 0.41 and not more than 0.55.

25. The liquid transporting apparatus according to claim **22**, wherein each of the pressure chambers has a shape long in a predetermined direction; and

each of the driving zones is formed at least at two areas which are included in the area overlapping with the edge portion of one of the pressure chambers and which extend substantially in parallel to the predetermined direction.

26. The liquid transporting apparatus according to claim **22**, wherein the vibration plate is formed of a metallic material and serves as the common electrode.

27. The liquid transporting apparatus according to claim **22**, wherein the vibration plate is insulative at least on a surface of the vibration plate opposite to the pressure chambers; and

the common electrode is formed on the surface of the vibration plate opposite to the pressure chambers.

28. The liquid transporting apparatus according to claim **22**, wherein the vibration plate is insulative at least on a surface of the vibration plate opposite to the pressure chambers; and

the individual electrodes are formed on the surface of the vibration plate opposite to the pressure chambers.

29. The liquid transporting apparatus according to claim **22**, wherein the piezoelectric layer is formed to overlap entirely with the pressure chambers as view of in the direction perpendicular to the plane.

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